Annales Societatis Geologorum Poloniae (2004), vol. 74: 125–196.

BIOSTRATIGRAPHY AND SEQUENCE STRATIGRAPHY OF THE LOWER CRETACEOUS IN CENTRAL AND SE POLAND

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Dziadzio, P. S., Gaździcka, E., Ploch, I. & Smoleń, J., 2004. Biostratigraphy and sequence stratigraphy of the Lower Cretaceous in central and SE Poland. *Annales Societatis Geologorum Poloniae*, 74: 125–196.

Abstract: Detailed biostratigraphy and sequence stratigraphy of the Lower Cretaceous deposits in central and southeastern Poland (the Warsaw and Lublin troughs and the Carpathian Foredeep) were established and refered to the cyclicity nature of the sedimentary basins filling. The surfaces of transgression and maximum flooding, and sequence boundaries were identified on the grounds of geophysical well-logs analysis, including: gamma (G), neutron (N), spontaneous potential (SP), and resistivity (R) logs. The analysis allowed us to distinguish sedimentary sequences of various scales and to correlate them precisely throughout the studied area. The chronostratigraphic framework was based on analyses of ammonite, microfauna and calcareous nannoplankton assemblages analysed in the same series. Mixed, Tethyan and Boreal macro- and microfauna allowed us to identify biostratigraphic zones of both, the Tethyan and Boreal realms. The recognised boreal ammonite zones included *robustum*, *heteropleurum* (lowermost Valanginian), *polytomus-crassus*, *triptychoides* (Upper Valanginian), *amblygonium*, *noricum* (Lower Hauterivian) and *gottschei* (Upper Hauterivian), as well as the Tethyan zones, such as *petransiens* (Lower Valanginian), *verrucosum* (Upper Valanginian) and *radiatus* (Upper Hauterivian). Eight foraminiferal assemblages were identified in the studied series. Some of them were correlated with the six Berriasian and Valanginian ostracod zones: *Cypridea dunkeri*, *C. granulosa*, *C. vidrana*, *Protocythere propria emslandensis*, *P. aubersonensis* and *P. frankei*. Thirteen calcareous nannoplankton zones have been distinguished, in reference to the stratigraphical zonal scheme of the Lower Saxony Basin.

The microfossil data allowed us to recognise the position of the Jurassic/Cretaceous boundary. It was correlated with a sequence boundary by analysis of geophysical logs. This boundary was identified along the studied area, over a distance of more than 170 km. Genetically controlled third order sedimentary sequences (parasequences) were described in the Lower Cretaceous, which record the progress of the sedimentary basins filling. A local curve of relative sea-level changes presented in this paper was correlated with a global one. A reconstruction of depositional sequences allowed us to indicate periods of tectonic activity in the studied area, adjacent to the Teisseyre-Tornquist Zone.

Key words: biostratigraphy, ammonites, foraminifers, ostracods, calcareous nannofossils, depositional systems, sequence stratigraphy, Lower Cretaceous, central and southeastern Poland.

Manuscript received 1 April 2003, accepted 27 April 2004

INTRODUCTION

Lower Cretaceous succession in the Polish Lowlands has been hitherto studied with respect to both stratigraphy (e.g., Marek, 1968, 1969; Marek & Raczyńska, 1973, Raczyńska, 1979), depositional systems, and cyclicity of sedimentation (Leszczyński, 1997). However, except for the Valanginian of the Tomaszów Trough (Kutek *et al.*, 1989) and the Middle and the Upper Albian of the Annopol area (Kutek & Marcinowski, 1996b), no other biostratigraphic zones comparable to the current stratigraphic schemes applied for the Lower Cretaceous in Europe, have been distinguished. Lack of precise stratigraphic framework of the discussed succession precluded the proper correlation of depositional sequences, as well as reconstruction of depositional history. Progress in the Cretaceous biostratigraphy during the last decade and new methods applied, e.g., sequence stratigraphy, enabled the authors to determine precisely the stratigraphic position of particular Lower Cretaceous sedimentary successions and to correlate them within the area of central and southeastern Poland.

Lack of the Lower Cretaceous exposures within the Polish Lowlands limited the studied material to drill-cores, representing only cored intervals of sections. Well log analysis was, therefore, important for reconstruction of primary successions of the basin fill. The gamma-ray (GR), neutron (N), spontaneous potential (SP) and resistivity (R) logs were used to distinguish parasequences, parasequence sets and depositional sequences, and their boundaries, enabling interpretation of the observed cyclicity and inferred relative sea-level changes. Finally, the distinguished parasequences and sequences permitted a precise correlation of sedimentary series within the studied area. The chronostratigraphic framework of the reconstructed events was established basing on analysis of ammonite, microfaunal and calcareous nannoplankton assemblages. Study of various fossil groups from the same strata served to improve the resolution of the stratigraphic divisions.

The southern part of the Jura Mountains, some Alpine units and the adjacent regions of southern France, belonging to the Tethyan Realm, became the area of the fundamental research on the Lower Cretaceous stratigraphy. The stratigraphic scheme elaborated in the stratotypes of particular stages is based on the succession of thermophilic taxa described as "Mediterranean" ones. An independent stratigraphic scheme, based on different faunal assemblages, was established for the Boreal Realm. Palaeogeographic position of the Polish Basin, located between the Tethys and the Boreal basins, was perfectly reflected in the composition of assemblages of cephalopods, foraminifers, ostracods, and calcareous nannoplankton in the Lower Cretaceous strata, registering influences of both provinces. Due to their mixed, tethyan-boreal nature, these assemblages are crucial for correlation of the stratigraphic schemes from both palaeogeographic realms.

Another problem discussed in the present paper was the palaeontological evidence of the Jurassic–Cretaceous boundary and its unequivocal identification in the non-cored parts of well sections. In the Polish Lowlands sections this boundary was established according to the schemes of the Boreal Realm and it was placed between the Volgian stage, developed as the Purbeckian facies, and marine series of the Ryazanian stage (e.g., Dembowska & Marek, 1976; Marek & Raczyńska, 1973; Marek *et al.*, 1989). In the Tethyan Realm, this boundary is located between the Tithonian and Berriasian stages and it nearly corresponds to the boundary between the Middle and the Upper Volgian, thus being a few million years older than in the Boreal Realm. Decision of the International Commission on Stratigraphy (ICS) accepting the Tethyan divisions as the obligatory ones requires reinterpretation of the Jurassic– Cretaceous boundary in the Polish Lowlands basins. The facies character of the sediments, developed as shallow-water carbonate-siliciclastic rocks with evaporites, excluded direct application of the Tethyan divisions based on ammonites due to lack of such fauna, but micropalaeontological data have been used successfully for stratigraphic subdivision and correlation. Consequently, both the wire-line logs analysis and biostratigraphic results enabled recognition of the Jurassic–Cretaceous boundary over the whole studied area.

The present paper focuses on a precise definition of stratigraphic position of the Lower Cretaceous sedimentary series, and its correlation within central and southeastern Poland. Interpretation of depositional sequences allowed defining relative and eustatic sea-level changes responsible for the observed cyclicity of the basin fill, as well as to reveal some episodes of tectonic activity in the studied area.

STUDY AREA

The Early Cretaceous sedimentary basin in the Polish Lowlands has developed along the margin of the East European Platform, extending in the NW–SE direction (Dadlez *et al.*, 1998). Its evolution was mainly controlled by extensional tectonic activity of the Teisseyre-Tornquist Zone, best manifested by increased subsidence of the area known as the Mid-Polish Trough (Fig. 1A). Tectonic activity of the Mid-Polish Trough was clearly marked from the Permian to the end of Cretaceous, with extensional regime prevailing at least until the Albian (Kutek, 2001) or Turonian (Hakenberg & Świdrowska, 1998). Mobility of the Mid-Polish Trough basement markedly influenced the sedimentation rate in the Early Cretaceous basins, which was reflected in the variable thickness and facies of the deposits. Thickness of the Lower Cretaceous within central and southeastern Poland varies from over five hundred to a few tens of metres, with maximum in the trough axis. There are also deep marine deposits, while more shallow ones are known from the East European Platform. Estimating of primary thickness of deposits and extent of sedimentary basins is difficult because of erosion that succeeded an inversion of the Mid-Polish Trough. Intraformational hiatuses caused by the Early Cretaceous synsedimentary tectonic movements were observed in the whole Lower Cretaceous sequence (cf. Hakenberg & Świdrowska, 1998). Facies differentiation of the Lower Cretaceous sedimentary series displays a latitudinal pattern (Fig. 1C). The southeastern part of the basin was dominated by carbonate sedimentation, while siliciclastic deposits prevailed in the central and northwestern parts, except of the Lower Berriasian developed as extremely shallow-water carbonate and evaporite facies and widespread over the whole area, from Eastern Pomerania to the southeastern part of Lublin region.

MATERIAL AND METHODS

The present paper deals with selected areas of central and southeastern Poland, defined as: the Warsaw and Lublin Troughs, and the Carpathian Foredeep (Fig. 1B). Cores and wire-line logs of the wells: Gostynin IG 1, Gostynin IG 3, Gostynin IG 4, Żychlin IG 3, Łowicz IG 1, Korabiewice IG 1, Warka IG 1, Białobrzegi IG 1, Bąkowa IG 1, Potok IG 1, Narol IG 1, Narol IG 2, Wiewiórka 4, Wola Wielka 2, Dębica 2, Stasiówka 1, Ropczyce 7, Zagorzyce 7, Zagorzyce 6, and Nawsie 1 were examined for purposes of bio- and sequence stratigraphy.

Investigations included the analyses of ammonites, microfauna (foraminifers and ostracods), as well as calcareous nannofossils. These studies resulted in discerning of biostratigraphic zones, and thus in the determination of stratigraphic position of individual sedimentary successions. The most important results of palaeontological studies are shown in Figs 2–32.

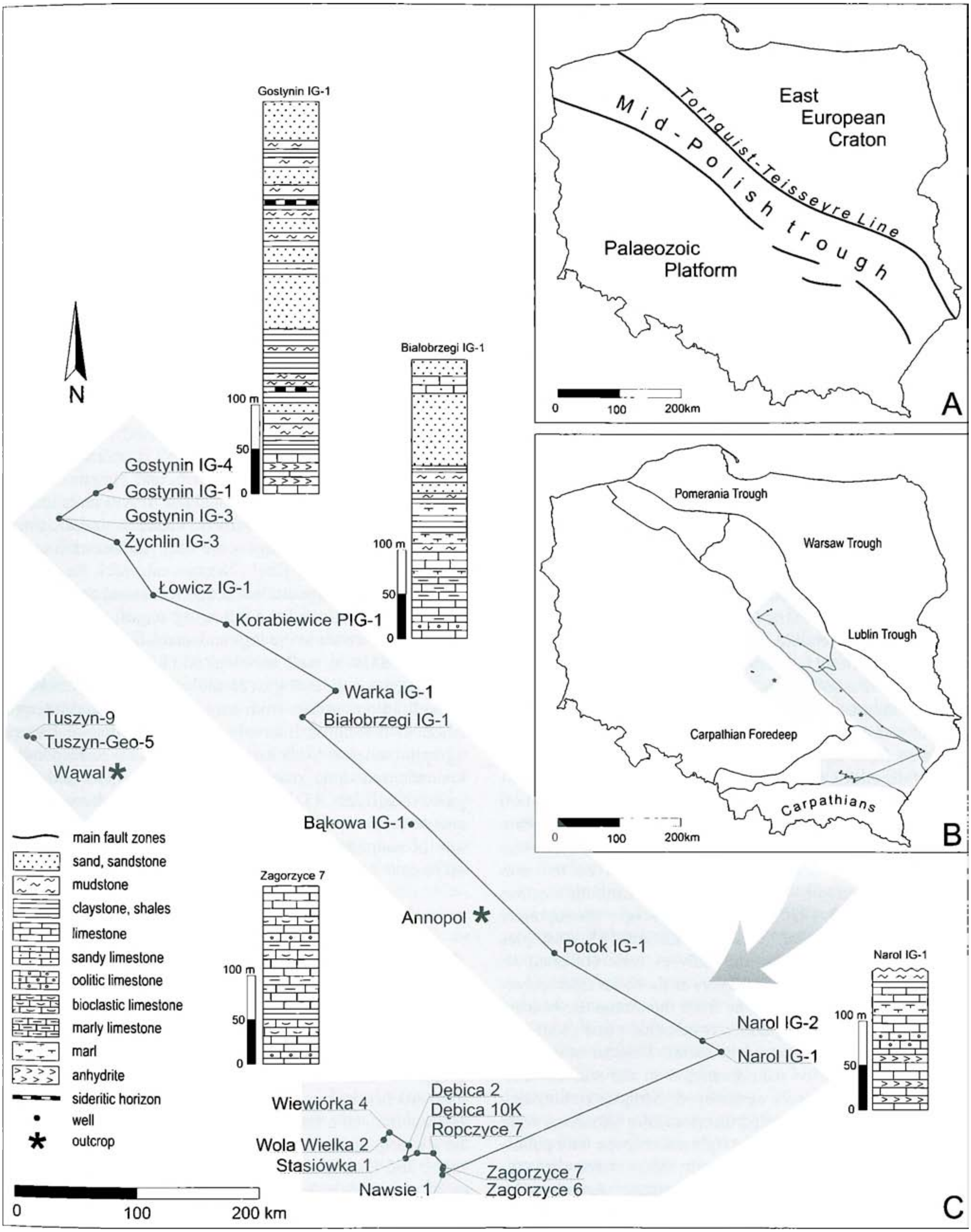


Fig. 1. A. Palaeotectonic map of Poland showing the main structural elements within the Polish Basin; B. Location of the studied area relative to the present-day tectonic units; C. Location of studied boreholes, outcrops and correlation profiles, lithology of the Lower Cretaceous within the studied area

The ammonites were collected also from the outcrops at Wąwał near Tomaszów Mazowiecki and from cores of Tuszyn 9 and Tuszyn Geo-5 wells, located within the Tomaszów Trough (comp. Fig. 1C). They also came from the Professor S. Marek's collection housed in the Geological Museum of the Polish Geological Institute (abbreviated MuzPIG), from the collections of the Faculty of Geology, University of Warsaw (abbreviated IGP), and the Institute of Palaeobiology Polish Academy of Sciences in Warsaw (abbreviated ZPAL), as well as from the private collection. These collections include specimens gathered by: R. Marcinowski, A. Radwański, C. Kulicki, J. Kutek, J. Dzik, A. Kaim, T. Praszkier and K. Dembicz. The specimens from the J. Dzik's collection are labelled – ZPAL Am IX, those from the K. Dembicz and T. Praszkier's collection – x, while the collections of C. Kulicki, J. Kutek, R. Marcinowski, A. Radwański, and the author (I. Ploch) have catalogue numbers of the Faculty of Geology Museum, Warsaw (IGP). Comparative studies on the Lower Cretaceous ammonites from the Polish and the Lower Saxony basins were carried out by I. Ploch at the Geological Institute in Hannover, and at the Ruhr-Universität in Bochum (collections of J. Mutterlose, M. Wippich and K. Kessel). Also the private collection of K. Wiedenroth, including the ammonites from German basins, was studied for the same comparative purposes. The collections of ammonites from the Tethys Realm were studied at the Geological Museum of the Dolomieu Institute, Grenoble, and at the Geological Museum of the Claude-Bernard University in Lyon, including the S. Reboulet's private collection.

The samples for micropalaeontological studies of foraminifer and ostracod assemblages, 0.5–0.8 kg each, were collected from the fully cored intervals and the sampling density depended on the core size and lithological variability (each metre on the average, locally more densely). Hard rocks were disintegrated using sodium sulphate decahydrate (Glauber's salt), while soft ones were only washed with water. The disintegrated material was washed on 0.1 mm meshes. Photographs were taken using scanning electron microscope LEO 1430, at the Microscope Photography Laboratory of the Polish Geological Institute. Most samples for calcareous nannoplankton analyses were collected simultaneously from the same layers as those for micropalaeontological studies, as well as from the ammonite-bearing deposits. The only exception was carbonate-free sediments from which samples were not collected. Because of the relatively low amount of nannoplankton in the studied sediments, the samples were centrifuged. Samples rich in clay minerals were earlier treated ultrasonically. Analyses were made using OLYMPUS BH-2 light microscope with polarization and phase contrast equipment. Smear slides were prepared following the standard techniques described by Perch-Nielsen (1985). Selected samples were also examined using scanning electron microscope LEO 1430, where from coccolith micrographs (Figs 26–31) were taken as well.

Calcareous nannoplankton was studied in the sections of eleven wells in central and southeastern Poland. Additionally, some samples from the outcrops at Wąwał and Annopol were analysed because of expected correlation of nannoplankton and ammonite zones. The amount of nannofossils ranged between very low and relatively high in the studied samples. Some coccolith assemblages, especially from the younger (Hauterivian–Aptian) deposits were abundant and taxonomically diversified. Also the preservation of nannoflora was different in individual sedimentary units and regions, e.g., coccoliths from the Lower Aptian of Białobrzegi IG 1 well became heavily dissolved (Fig. 30), whereas those from the Upper Albian of Annopol quarry and Bąkowa IG 1 well showed rather an overgrowth of calcite crystals (Fig. 31). Some samples, especially those from black and low-carbonate shales or coarse clastic sandstones, did not contain coccoliths at all.

Simultaneously with the biostratigraphical studies, a detailed analysis of wire-line logs was performed. The set of original logs of gamma-ray (GR), neutron (N), spontaneous potential (SP), and resistivity (R) was digitized for this analysis. Digital wire-line logs of the following wells from the peri-Carpathian area were also used: Wiewiórka-4, Wola Wielka-2, Dębica-2, Stasiówka-1, Dębica-10K, Ropczyce-7, Zagorzyce-6, Zagorzyce-7, and Nawsie-1. Most logs were normalized and recalculated to API units to standardise geophysical measurements made at various times. The following sets of logs were used for correlation and presentation: Gamma Ray – Neutron and SP – Resistivity. Interpretation of depositional sequences based on geophysical well data included the following stages: (1) identification of main trends in the logs and analysis of their nature in juxtaposed GR as well as N logs and logs of SP and R (accounting for caliper log), (2) calibration of log variability using lithological data from core descriptions and interpretation of non-cored intervals, (3) introduction of biostratigraphic scheme, (4) delineation of intervals corresponding to condensed strata, maximum flooding surfaces and transgressive surfaces, (5) distinction of parasequences, parasequence sets, sequences, and their boundaries, (6) interpretation of supposed facies changes, and (7) interpretation of sedimentation cyclicity in the Lower Cretaceous section.

LOWER CRETACEOUS STRATIGRAPHY – STATUS QUO

Previous stratigraphic studies of the Lower Cretaceous in Poland included both biostratigraphy, based on various groups of macro- and microfossils, and lithostratigraphy used mainly in non fossiliferous sedimentary sequences. Ammonites – the orthostratigraphic group – provided base for a stratigraphic scheme of the Upper Berriasian, Valanginian, and Hauterivian (Marek & Raczyńska, 1973; Marek *et al.*, 1989; Marek & Rajska, 1997; Kutek *et al.*, 1989; Marcinowski & Wiedmann, 1985, 1990), whereas stratigraphy of the Lower Berriasian, that includes Purbeckian facies lacking ammonites, was based on ostracods (Bielecka & Sztejn, 1966; Marek *et al.*, 1989). Micropalaeontological methods were also applied to the younger Lower Cretaceous sequences (Moryc & Waśniowska, 1965; Kubiatowicz, 1983; Sztejn, 1984; Gaździcka, 1993). Lithostratigraphic zonation of the Lower Cretaceous deposits in the

Polish Lowlands was elaborated by Raczyńska (1979), and Marek and Raczyńska (1979). Lithostratigraphic scheme of the Radom–Lublin area was recently modified by Marek (1997). This scheme includes both formal and informal units: formations and members. A formal subdivision of the Lower Cretaceous was established in central and north-western Poland (mainly in the Kujawy region), while an informal one within the southeastern Poland. In the study area (Warsaw and Lublin Troughs), it is difficult to distinguish these lithostratigraphic units because of differences in facies development between them and the stratotype sections.

An argillaceous-marly succession with beds of *Cyrene* coquinas are considered as the oldest Lower Cretaceous deposits in central Poland. It is recognised as the Skotniki Member of the Kcynia Formation, which includes mainly the Upper Jurassic carbonate-siliciclastic series with evaporites (Marek, 1997). The stratigraphic position of this sedimentary series was established as the lowermost Ryazanian (ostracod Zone A), corresponding to the *runctoni* ammonite Zone in the Boreal Province or to the *jacobi-grandis* Zone in the Tethyan Province (Marek & Rajska, 1997). This statement, however, contains a major inconsistency as the Boreal *runctoni* Zone is correlated with the Tethyan *occitanica* Zone and not with the *jacobi* or *jacobi-grandis* zones (Haq *et al.*, 1988; Bown *et al.*, 1999). It corresponds, thus, to the higher part of the Lower Berriasian or the Middle Berriasian, while the *jacobi-grandis* ammonite Zone includes the uppermost Tithonian and the lowermost Berriasian. Also Leszczyński (1997) placed the deposits of the Skotniki Member in the Upper Volgian and the lowermost Berriasian, what contradicts the previous estimation of its stratigraphic position as the lowermost Ryazanian. In the Mazowsze (Mazovia) region, where sedimentary series of the Purbeckian type are widely distributed and are quite thick (e.g., more than 110 m in Gostynin IG 3 and Żychlin IG 3 wells), the presence of the ostracod Zone A was not confirmed. The Skotniki Member is there distinguished, however, based on lithological and facies characteristics of the sediments. Arenaceous limestones, sandstones with siderites and ferruginous oolites, overlie the Skotniki Member, dominated by argillaceous sediments, and mudstones or claystones with marine invertebrates and plant remains. This series is distinguished as the Rogoźno Formation including the Kajetanów, the Zakrzew, and the Opoczki members. The Kajetanów Member, in which no ammonites have hitherto been found, is considered to represent the highest part of the Lower Berriasian. The siliciclastic sediments of the Zakrzew Member contain mixed – Tethyan-Boreal – ammonite assemblage. They have been described as the "Beds with *Riasanites*, *Himalaites* and *Picteticeras*" and are correlated with the Tethyan *occitanica* and *boissieri* (lower part) zones, that comprise the Middle and Upper Berriasian (Marek & Rajska, 1997). On the grounds of ammonites, the Opoczki Member, including sandstones, claystones, clayey shales with sphaerosiderites, mudstones with ferruginous ooids and pyritized plant remains, was correlated with the Upper Berriasian ("Beds with *Surites*, *Euthymiceras* and *Neocosmoceras*") and the lowermost Valanginian ("Beds with *Platylenticeras*, *Neocomites* and *Karakaschiceras*") (Marek & Rajska, 1997).

The alternating sandy and clayey-sandy succession, overlying the Opoczki Member was distinguished as the Bodzanów Formation, and determined on the grounds of ammonites as the higher part of the Lower Valanginian ("Beds with *Polyptychites*"). Also the Włocławek Formation, corresponding to the Upper Valanginian ("Beds with *Dichotomites* and *Saynoceras*"), and Lower ("Beds with *Endemoceras*") and Upper Hauterivian ("Beds with *Simbirskites*") comprises alternating clayey-mudstone and arenaceous packages. The deposits contain numerous marine molluscs – bivalves and ammonites, but also plant debris and accumulations of chamoisite-goethite ooids. Siderite concretions are abundant in some horizons. The Włocławek Formation includes three individual and formally defined units, called: Wierzchosławice, Gniewkowo and Żychlin members (Raczyńska, 1979). The formal lithostratigraphic scheme has also been introduced for the younger Lower Cretaceous succession, referred to the Barremian, Aptian and Lower Albian. This thick, tripartite complex was designated as the Mogilno Formation (Raczyńska, 1979). Its lower and upper members are formed mostly by sandstones (Pagórczany and Kruszwica members), while the middle one includes claystones and mudstones (Gopło Member). Thus, the Lower Cretaceous sedimentary series in central and north-western Poland are dominated by siliciclastic, fine- and coarse-grained deposits.

Beginning from the southern border of the Warsaw Through, including Magnuszew and Radom blocks, towards the southern part of the Lublin Upland, siliciclastic facies gradually change into carbonate ones. Within Lubaczów region, the Lower Cretaceous is developed as shallow-water, often bioclastic and oolithic limestones, sandy marls or calcareous sandstones. However, towards the axial part of the Mid-Polish Trough (the NE margin of the Holy Cross Mountains) the amount of siliciclastic material in sediments increases considerably. Marls with intercalations of claystones or fine-grained sandstones with argillaceous matrix and levels of siderites and chamoisite-goethite ooids dominate within this area. Then, the Lower Cretaceous in SE Poland requires a lithostratigraphic division different from that in central Poland. The Białobrzegi Formation in the NE margin of the Holy Cross Mountains up to the Magnuszew and Radom blocks, and the Cieszanów Formation in the Lubaczów area are equivalents of the Włocławek Formation distinguished within Kujawy region (Marek, 1997). These formations include mainly the Upper Valanginian and Hauterivian deposits, according to the hitherto accepted stratigraphic interpretation (Marek, 1997). Sands and sandstones with glauconite and phosphorite nodules in the upper part, which overlie the above-described sedimentary series, are included into the Mogilno Formation. Its stratigraphic position was determined as the Barremian–Middle Albian. It should be noted, however, that the Lower Cretaceous stratigraphy in this area was hitherto inadequately recognized. Isolated caps of the Lower Cretaceous deposits were also documented in the Carpathian Foredeep, near Dębica and in the basement of Carpathian nappes (Fig. 1). These series include shallow water carbonates and marly-carbonate rocks, deposited in lagoons, barriers, tidal flats, shoals, and platform margins (Maksym *et al.*, 2001). They are attributed to the Ropczyce and Dębica Series, of the Berriasian and Valanginian age (Moryc, 1997; Zdanowski *et al.*, 2001).

RESULTS OF BIOSTRATIGRAPHICAL STUDIES

AMMONITE BIOSTRATIGRAPHY

Drill cores from central and southeastern Poland provided significant palaeontological evidence of the Lower Cretaceous ammonites. They are especially abundant and well preserved within the Berriasian and Valanginian deposits (Figs 2, 3). Nevertheless, only the exposure at the Wąwał clay-pit near Tomaszów Mazowiecki provided rich palaeontological material suitable for a detailed study of the ammonite assemblages succession. The peculiar palaeogeographic position of the Polish Basin, situated between the two major palaeogeographic provinces: Tethyan and Boreal ones, resulted in variable and alternating influences of them both. The ammonites have migrated to the Polish Basin from the south and/or from the north, according to predominant influences of either province. Because of a mixed nature of the ammonite assemblages found in the Lower Cretaceous sections, the Tethyan and the Boreal ammonite zonations are used in parallel.

The **Berriasian** ammonites were not revised in detail during this study. Until now two informal stratigraphic units were distinguished in the Berriasian strata within the Polish Lowlands: "Beds with *Riasanites*, *Himalayites* and *Picte-*

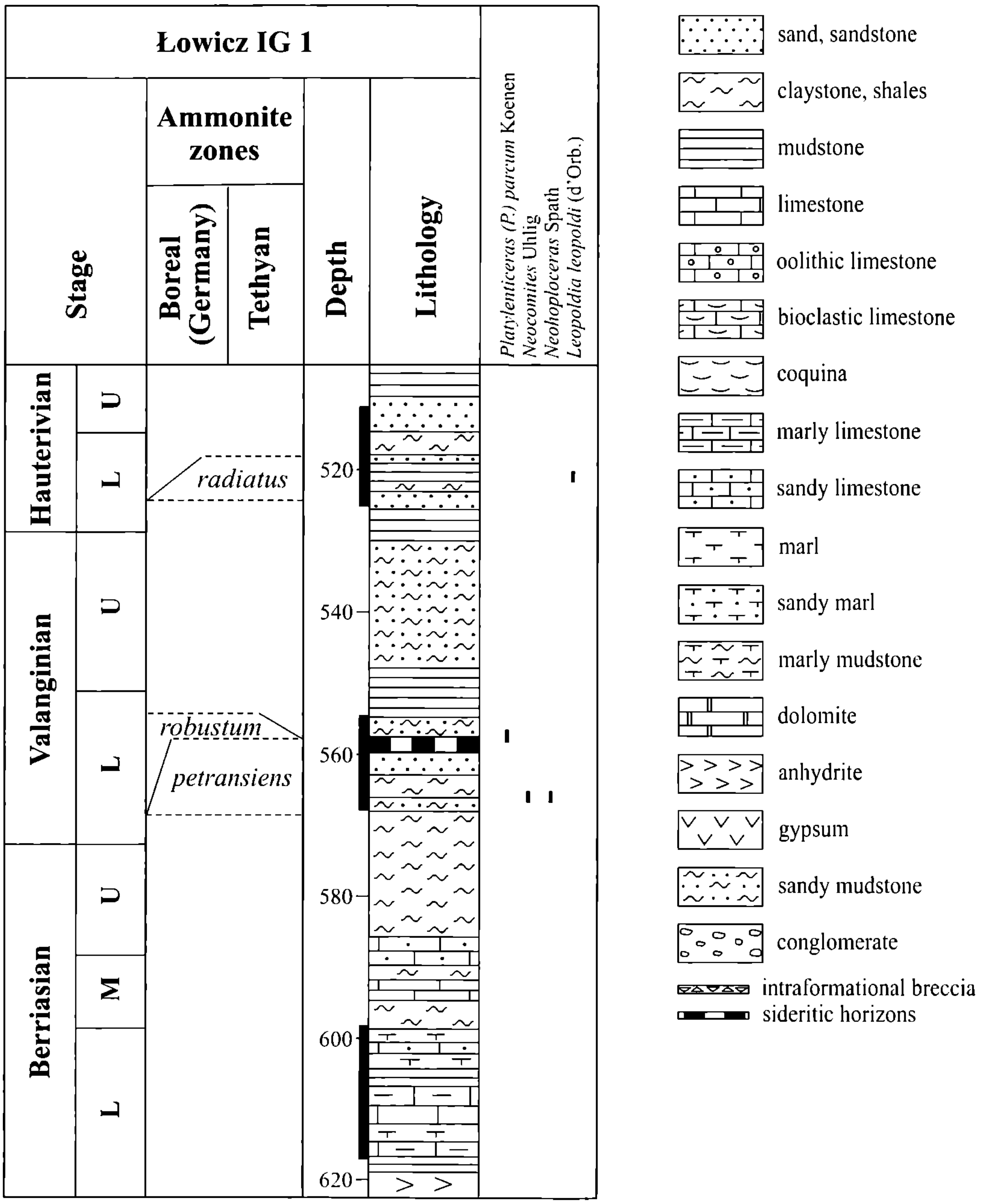


Fig. 2. Distribution chart of ammonites in the Lower Cretaceous deposits of the Łowicz IG-1

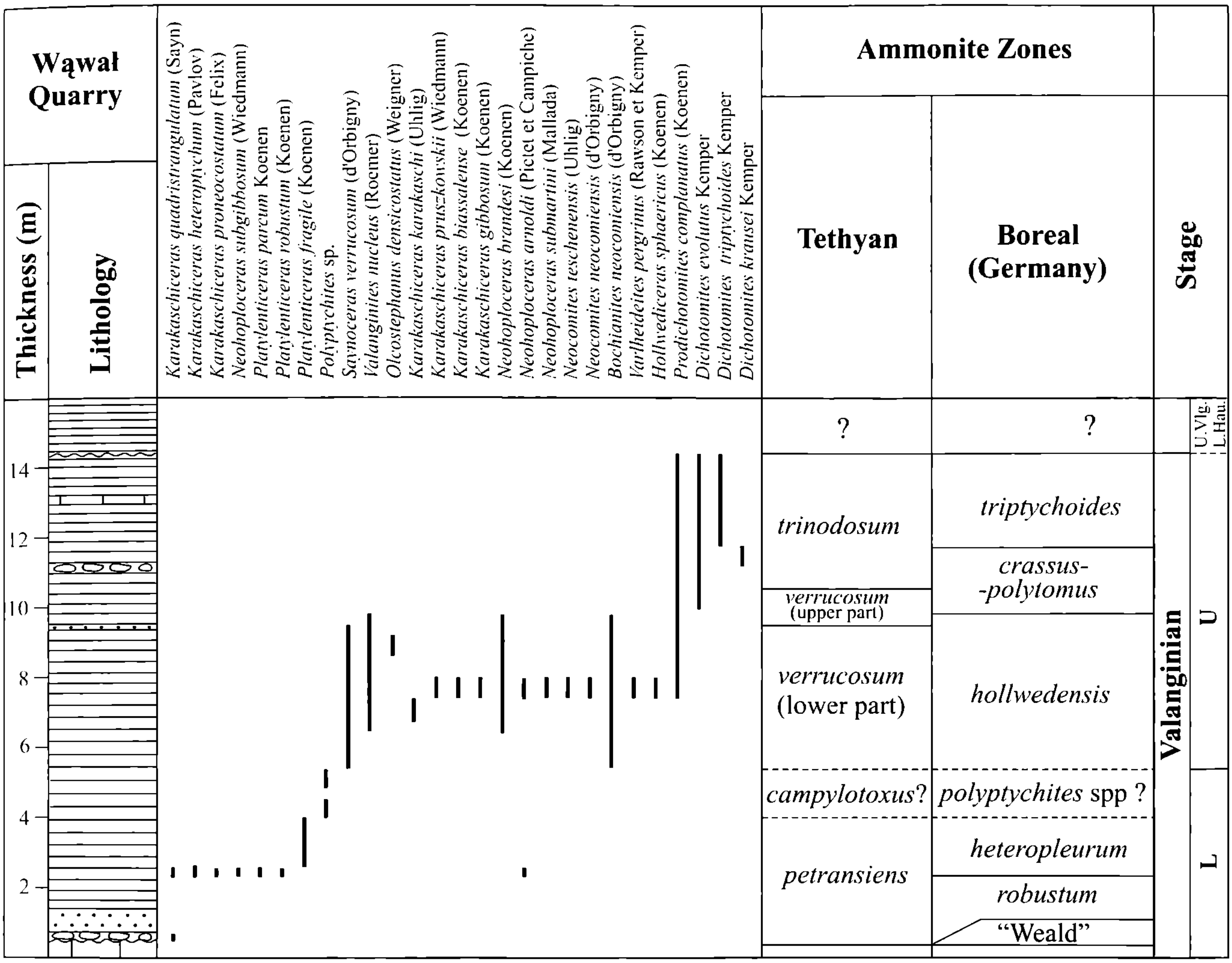


Fig. 3. Distribution chart of ammonites in the Lower Cretaceous deposits of the Wąwał clay-pit (after Kutek *et al.* 1989, Ploch this paper); for lithological description – see Fig. 2

ticeras", and "Beds with *Surites*, *Euthymiceras* and *Neocosmoceras*" (Marek, 1964, 1968, 1969, 1977a, 1983, 1997; Marek & Raczyńska, 1973, 1979; Marek & Shulgina, 1996). The lower unit – "Beds with *Riasanites*, *Himalayites* and *Picteticeras*" – was correlated with the Middle and the lower part of the Upper Berriasian and referred to the Tethyan *occitanica* Zone and to the lower part of the *boissieri* Zone (English *kochi* and *icenii* zones) (Marek & Shulgina, 1996; Marek & Rajska, 1997). The upper unit – "Beds with *Surites*, *Euthymiceras* and *Neocosmoceras*" – was referred to the upper part of the *boissieri* Zone (English *stenomphalus* and *albidum* zones) (Marek & Rajska, 1997; Marek *et al.*, 1989; Marek & Shulgina, 1996). Baraboshkin (1999) has questioned the presented scheme, pointing out that *Riasanites riasanensis* (Nikitin) on the Russian Platform occurs in the Upper Berriasian, so it may not be correlated with the Tethyan *occitanica* Zone. He also doubts the determinations of *Riasanites riasanensis* (Nikitin) specimens from Poland.

Within the Berriasian strata the ammonites are abundant and relatively well preserved. However, some specimens obtained from drill cores are crushed, what hinders their correct taxonomic identification. The *Neocomites neocomiensis* (d'Orbigny) and *Neocomites teschenensis* (Uhlig) (hitherto interpreted as *Neocomites* cf. *platycostatus* Sayn) were found in the cored sections from Koraczewko IG 1 (depth 153.3 m) and Kcynia IG 2 (depth 252.5-6 m). They have been found within the uppermost part of the sedimentary sequence hitherto assigned to the Berriasian. The following species that occurred in these sections were described from the Lower Valanginian: *Neocomites neocomiensis* (d'Orbigny), that appears in the *petransiens* Zone (e.g., Nikolov, 1960; Company, 1987; Reboulet, 1995), and *Neocomites teschenensis* (Uhlig) from the *campylotoxus* Zone (e.g., Nikolov, 1960; Company, 1987; Thieuloy *et al.*, 1990; Reboulet, 1995). The abundance of ammonite shells in the dark, argillaceous deposits of the uppermost Berriasian may indicate a decreasing of the accumulation rate (a condensed interval). As a result, the older, Berriasian ammonites are accompanied by the younger, Valanginian specimens. These ammonites may represent the earliest Valanginian taxa in the Mid-Polish Basin.

The lowermost **Valanginian** ammonites: *Neocomites* and *Neohoploceras* (Fig. 4A, B) were also found in cored section from Łowicz IG 1, at the depth 566.7 m (Fig. 2). They occur beneath the layer containing Boreal ammonites of the genus *Platylenticeras*. They are typical of the *robus-*

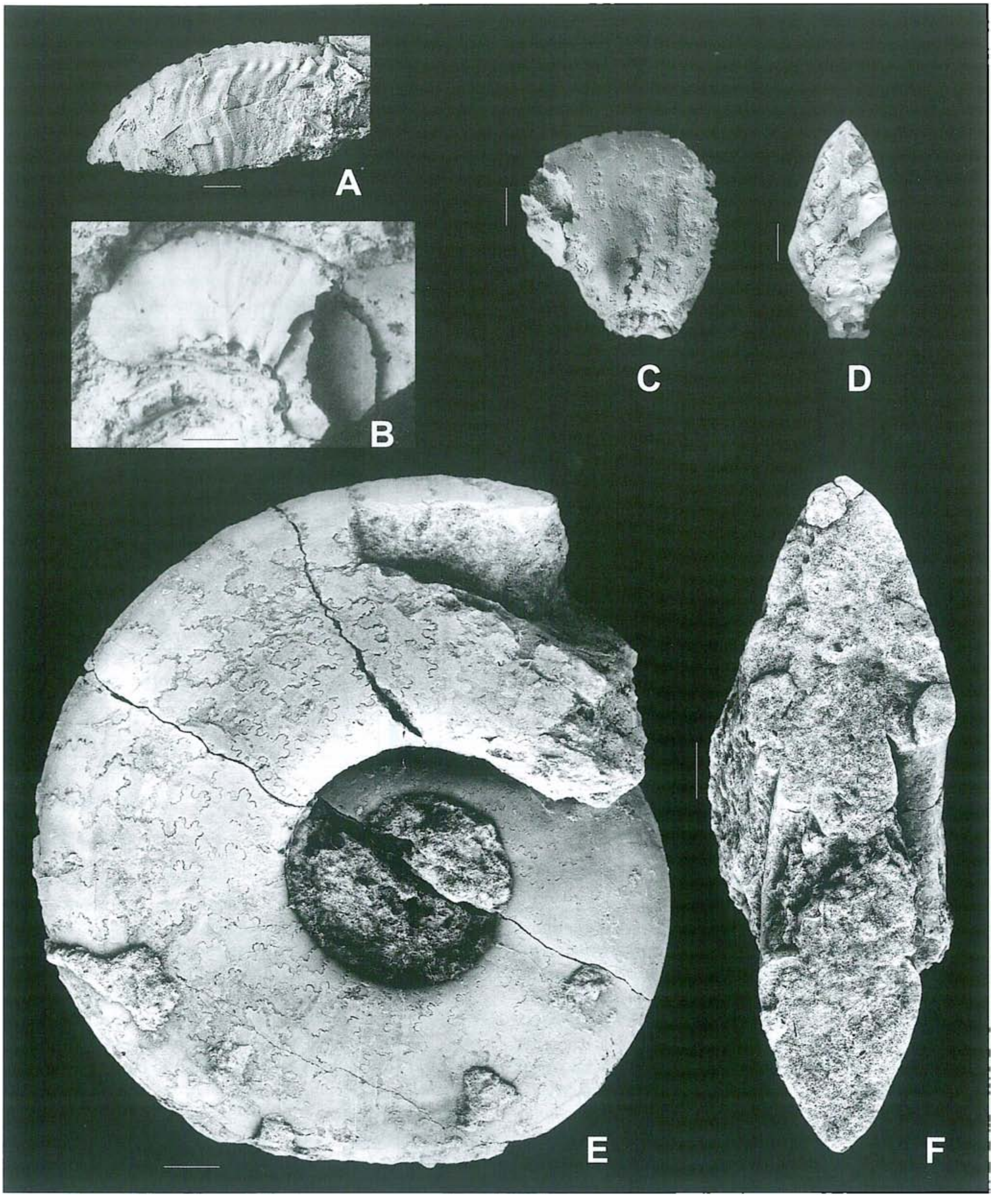


Fig. 4. **A.** *Neocomites* sp., nr IGP 11, Łowicz IG-1 (566.7 m), Lower Valanginian; **B.** *Neohoploceras* sp., nr Muz. PIG 1652.II.203, Łowicz IG-1 (566.8 m), Lower Valanginian; **C, D.** *Platylenticeras* (*Tolypeceras*) *fragile* Koenen, nr IGP BX.A.Wąwał, Lower Valanginian, *heteropleurum* Zone (O); **E, F.** *Platylenticeras* (*Platylenticeras*) *parcum parcum* Koenen, phragmocone, nr BX.A.Wąwał, Lower Valanginian, *robustum* Zone. Scale bar = 1 cm

tum Zone, that was established in the German Basin and correlated with the lowermost Valanginian (Kemper, 1961). In the mentioned well section, the horizon with *Neocomites* and *Neohoploceras* was hitherto included into the "Beds with *Platylenticeras*", while deposits with *Platylenticeras* – into the "Beds with *Polyptychites*" (Marek, 1986). The other early Valanginian species, *Karakaschiceras quadristrangulatum* (Sayn), was found in a similar stratigraphic position in the outcrop at Wąwał. It appears there also below the layers containing Boreal ammonites of the *robustum* Zone (Kutek *et al.*, 1989; Ploch, 2002). The stratigraphic position of the lowermost Valanginian ammonites was determined based on their occurrence in the sections and on their Valanginian character. They were always found below the ammonite assemblages of the *robustum* Zone (Figs 2, 3). The ammonites are correlated with those of the Mediterranean *petransiens* Zone, accepted as the lowermost Valanginian zone at the meeting of the Lower Cretaceous Working Group in 2002 (Hoedemaeker *et al.*, 2003). The earliest Valanginian ammonites reflect the Mediterranean influences marked in the Polish Basin since the Late Berriasian.

The next biostratigraphic zone distinguished in the studied sections is the *robustum* Zone (Fig. 32). A revision of the earlier collections and the new findings at the Wąwał outcrop allowed to identify the following species: *Platylenticeras (Platylenticeras) robustum robustum* (Koenen) (Fig. 5H, I), *Platylenticeras (Platylenticeras) parcum parcum* Koenen (Fig. 4E, F), and *Platylenticeras (Platylenticeras) parcum isterberense* Kemper (Ploch, 2002). The specimens of *Platylenticeras (Platylenticeras) parcum* Koenen were probably described as *Platylenticeras (Platylenticeras) gervilianum* (d'Orbigny) by previous authors (Lewiński, 1932; Kokoszyńska, 1956; Pruszkowski, 1962). Ammonites of the species *Platylenticeras (Platylenticeras) parcum* Koenen, found in the core section from Łowicz IG 1 (depths: 557.7 and 558.1 m), are also indicative of the *robustum* Zone. These sediments were hitherto included in the "Beds with *Polyptychites*" (Marek, 1986).

In the Wąwał section, a specimen of *Platylenticeras (Tolypeceras) fragile* Koenen (Fig. 4C, D) was found above the layers containing ammonites typical of the *robustum* Zone. Specimens of *Platylenticeras (Tolypeceras) fragile* Koenen were previously described as *Platylenticeras (Tolypeceras)* cf. *marcousianum* (d'Orbigny) (Lewiński, 1932; Kokoszyńska, 1956; Pruszkowski, 1962). In the Lower Saxony Basin, this species may occur in the *heteropleurum* Zone (Kemper, 1961, 1992). This zone is dubious in Poland, considering the lack of other fauna indicative of them. *Platylenticeras (Tolypeceras) fragile* Koenen possibly migrated from the Polish Basin to the Carpathian one. This supposition is based on the findings made in the West Carpathians and including the specimens described as *Platylenticeras* ex. gr. *marcousianum* (d'Orbigny) (Vašiček & Michalik, 1999) that could belong to this species. Besides the material from the Łowicz IG 1 well and from the exposure at Wąwał *Platylenticeras* was noted from the Szczecin Trough, within the north-western Poland (Marek & Raczyńska, 1979). Various species of *Platylenticeras* came into the Polish Basin from the German one. Tethyan ammonites are absent in this interval, contrary to the earlier suggestion. At the Wąwał section, *Karakaschiceras quadristrangulatum* (Sayn), *Karakaschiceras heteroptychum* (Pavlow), *Karakaschiceras pronecostatum* (Felix), and *Neohoploceras subgibbosum* (Wiedmann) occur above the ammonites of the *robustum* Zone or together with them. The interval would be correlated with the Tethyan *petransiens* Zone, what points out for the oldest occurrence of the genus *Karakaschiceras*, hitherto known from the Upper Valanginian, in the Tethyan Basin (Kutek *et al.*, 1989).

The "Beds with *Platylenticeras*, *Neocomites* and *Karakaschiceras*" were described as the oldest Valanginian strata of the Lower Cretaceous in extra-Carpathian Poland (Marek & Rajska, 1997). An informal unit, dominated by arenaceous sediments and corresponding to the "middle Valanginian", was distinguished above them and described as the "Beds with *Polyptychites*", mainly on the basis of their position between the "Beds with *Platylenticeras*, *Neocomites* and *Karakaschiceras*" and "Beds with *Dichotomites* and *Saynoceras*" (Marek & Rajska, 1997). These strata are interpreted as regressive, shallow, and locally limnic deposits because of their sedimentary features (Marek, 1969). Fauna is very rare in these strata. Fragments of ammonites described by earlier authors as *Polyptychites* sp. (Lewiński, 1930, 1932; Pruszkowski, 1962; Witkowski, 1969) were found in the Wąwał section. The lack of photographs and detailed descriptions of the earlier specimens precludes a revision of their determinations. These findings led to the inclusion of this part of the section into the "Beds with *Polyptychites*", and to correlate them with the Tethyan *campylotoxus* Zone (Fig. 32). Core data (mainly from Żychlin IG 1) provided incomplete and poorly preserved specimens (Fig. 5E–G), which can only be determined as *Polyptychites* sp., without the species attribution (Marek, 1968, 1984).

The appearances of *Saynoceras verrucosum* (d'Orbigny) (Fig. 5A–D) clearly mark the Upper Valanginian in the Wąwał exposure. This species characterizes the *verrucosum* Subzone, described also as the *verrucosum* horizon within the *verrucosum* Zone (Kutek & Marcinowski, 1996a). The core material has not provided unequivocally identifiable fossils of this ammonite species. The forms described as *Saynoceras verrucosum* (d'Orbigny) (Marek, 1969) are juvenile specimens that may belong to some other genus as well. Only in the core from Potok IG 1 (at the depth 239.0–239.35 m) *Valanginites nucleus* (Roemer) was found (Fig. 7G, H), which may be indicative of the *verrucosum* Zone. *Valanginites nucleus* (Roemer) (Fig. 7G, H) is abundant in the Wąwał outcrop. Boreal ammonites of genus *Dichotomites* appear above the last occurrence of *Saynoceras verrucosum* (d'Orbigny) in the higher part of the Wąwał section. This fact allowed referring this part of the section to the German ammonite zonation. The species: *Valanginites nucleus* (Roemer), *Neohoploceras brandesi* (Kenen), and *Dichotomites* are concurrent in the Wąwał section, in an interval *ca.* 0.5 m thick. The specimens of *Valanginites nucleus* (Roemer) in this part of the section differ from the earlier forms in their nearly smooth shell and greater dimensions. The same features are displayed by the terminal forms of this species in the Lower Saxony Basin (Kurt Wiedenroth, pers. comm., 2000). This indicates that they appeared in the Polish Basin together with ammonites of genus *Di-*

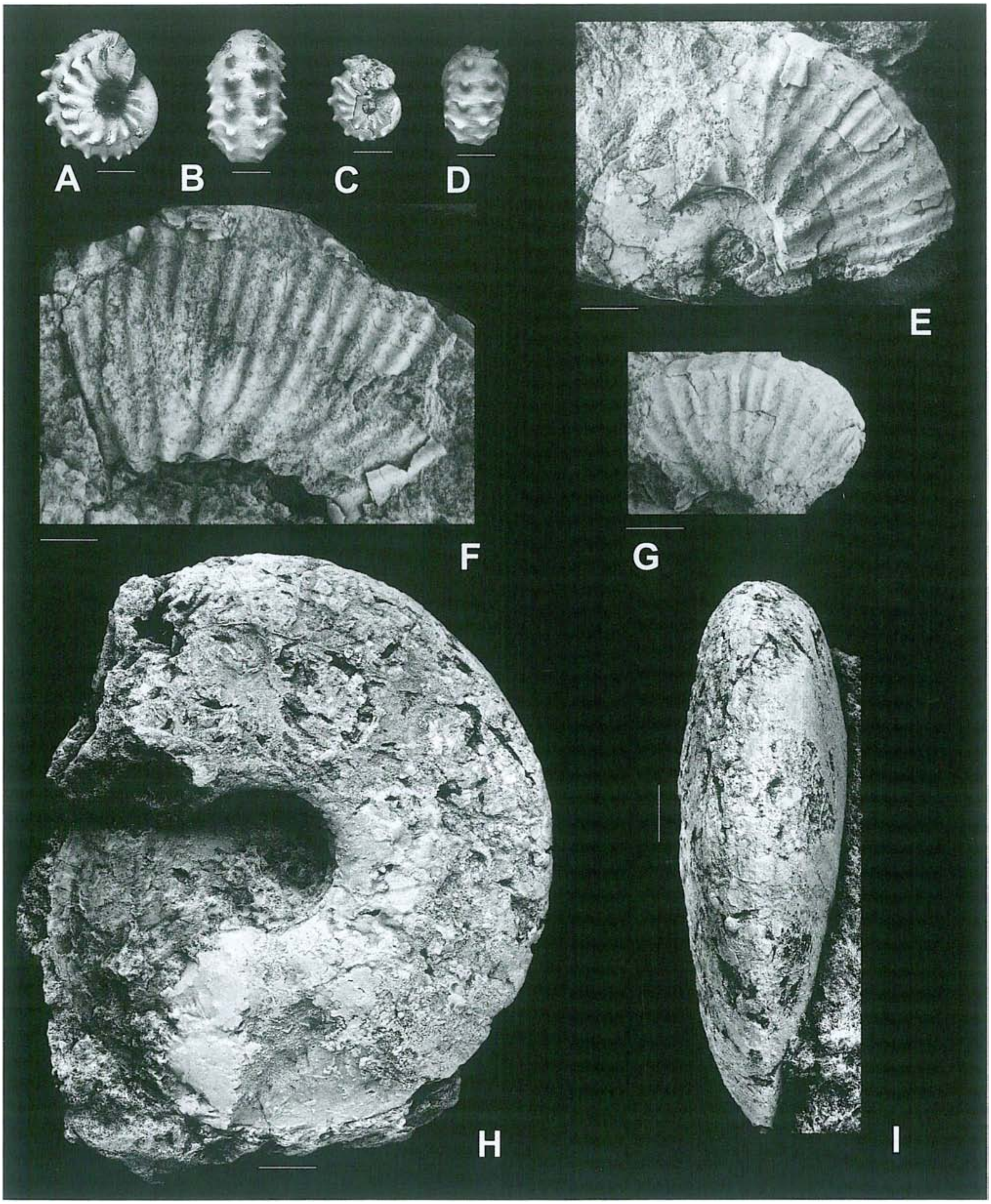


Fig. 5. **A, B.** *Saynoceras verrucosum* (d'Orbigny), body chamber, nr IGP [illegible] Wąwał, Upper Valanginian, *verrucosum* Zone; **C, D.** *Saynoceras verrucosum* (d'Orbigny), body chamber, nr IGP 23 [illegible] Wąwał, Upper Valanginian, *verrucosum* Zone; **E.** *Polyptychites* sp., nr Muz. PIG 1652 II 2046 Żychlin IG-1 (425.6 m), Lower Valanginian; **F.** *Polyptychites* sp., nr Muz. PIG 1652 II 2046 Żychlin IG-1 (421.7 m), Lower Valanginian; **G.** *Polyptychites* sp., nr Muz. PIG 1652 II 2054 Żychlin IG-1 (425.6 m), Lower Valanginian; **H, I.** *Platylenticeras* (*Platylenticeras*) *robustum robustum* (Koenen), phragmocone nr [illegible] Wąwał, Lower Valanginian, *robustum* Zone. Scale bar 1 cm

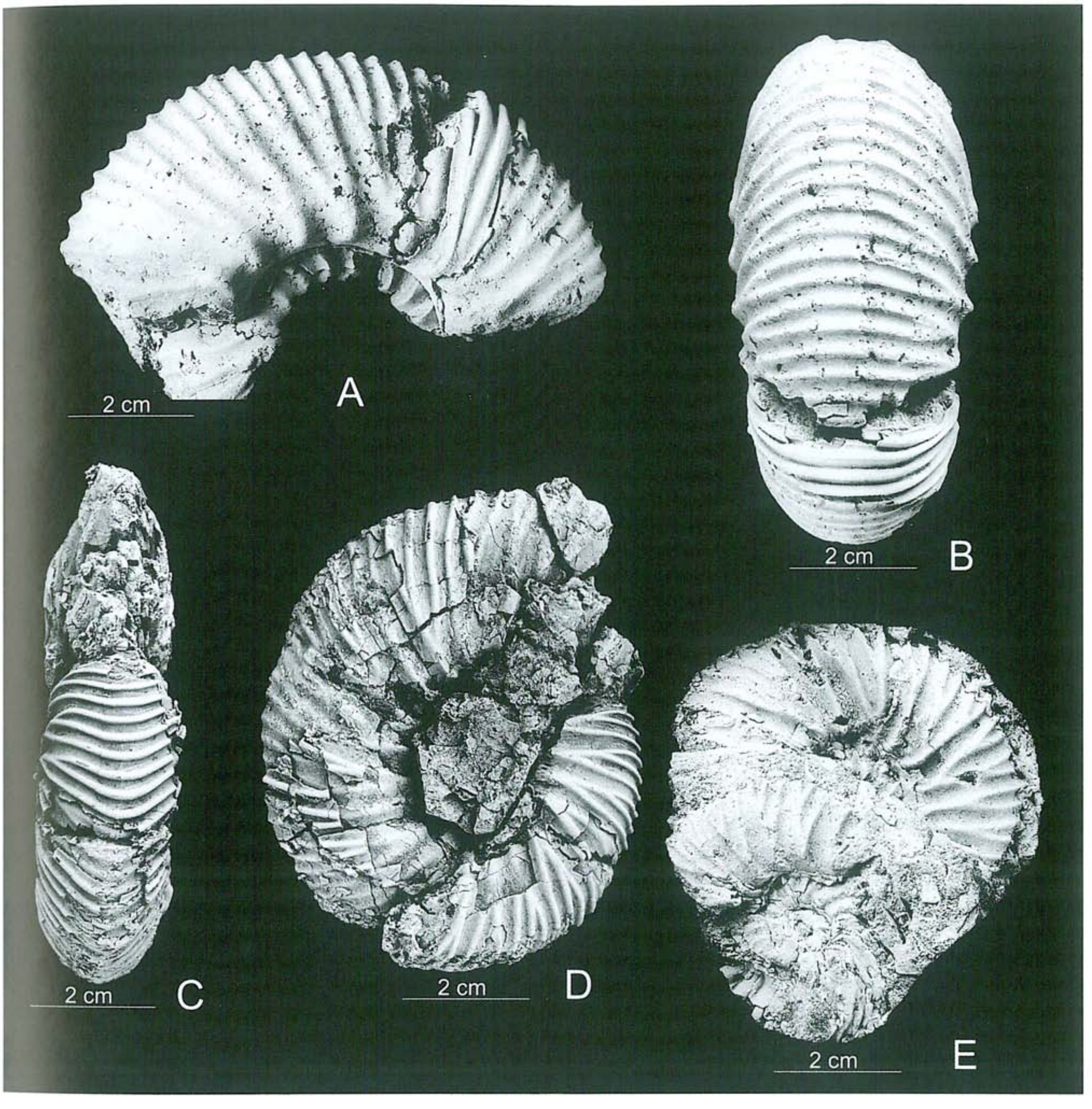
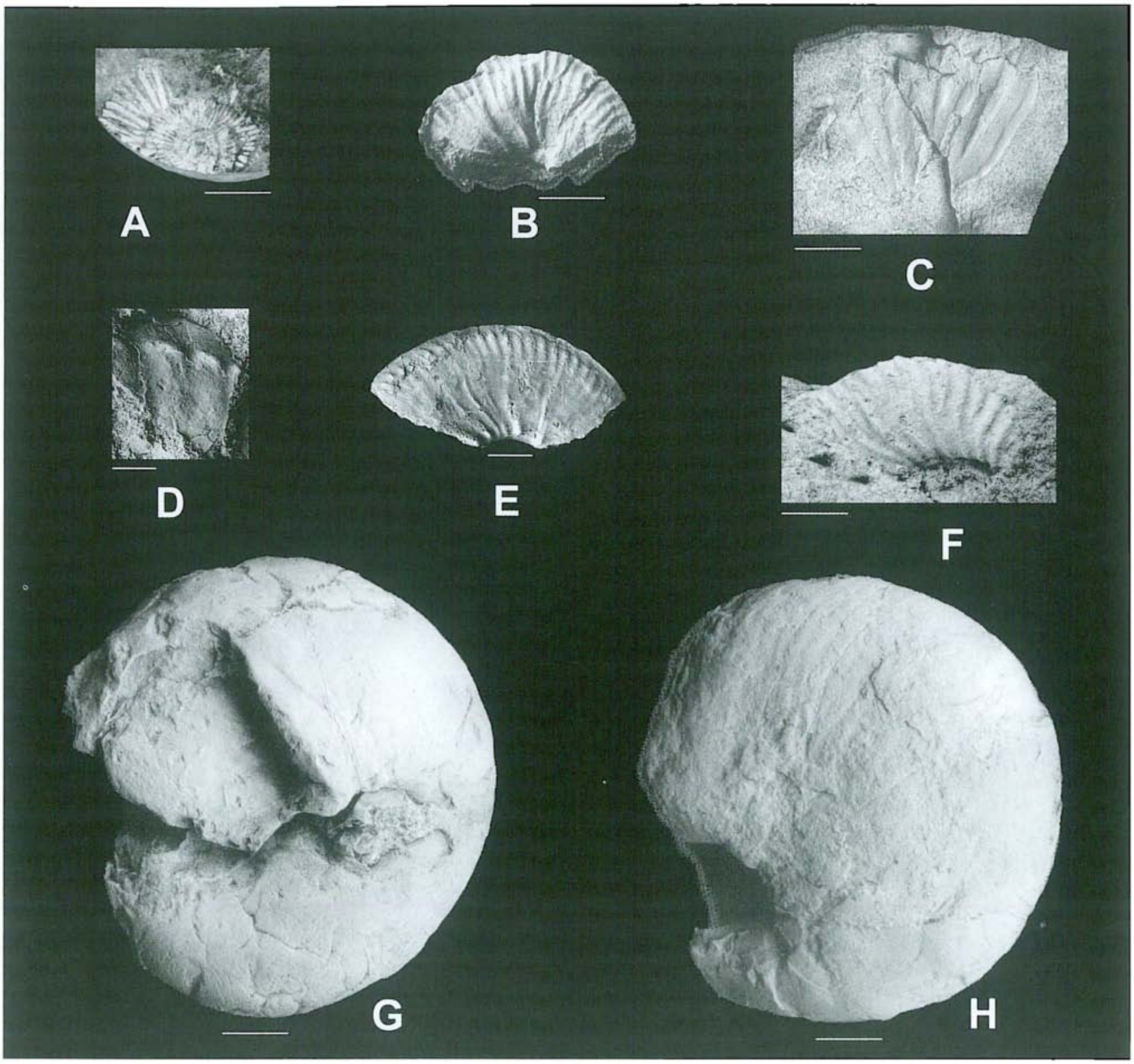


Fig. 6. A, B. *Dichotomites evolutus* Kemper, phragmocone, no. IGP [illegible], Wąwał, Upper Valanginian; **C, D.** *Dichotomites triptychoides* Kemper, no. IGP [illegible], Wąwał, Upper Valanginian, *triptychoides* Zone; **E.** *Dichotomites krausei* Kemper (smaller specimen); *Dichotomites evolutus* Kemper (larger specimen), no. IGP [illegible], Wąwał, Upper Valanginian, *crassus, polytomus* Zone

chotomites immigrating from the Lower Saxony Basin (Ploch, 2003). The range of this species in the Lower Saxony Basin reaches the *hollwedensis* Zone; hence, the described interval is attributed to this zone. The younger zones *crassus* and *polytomus* were combined because of the lack of precise location in the section of the nominal species *Dichotomites crassus* Kemper. The species: *Dichotomites evolutus* Kemper (Fig. 6A, B) occurring since the first appearance of genus *Dichotomites* in the Wąwał section) and *Dichotomites krausei* Kemper (Fig. 6E) occur in both horizons and cannot be used for their separation. *Prodichotomites complanatus* (Koenen) appears in the Wąwał section earlier than *Dichotomites*, and its range ends in the *triptychoides* Zone. In the Lower Saxony Basin, its range is limited to the *polytomus* Zone (Kemper, 1978).

The appearance of *Dichotomites triptychoides* Kemper in the Wąwał section (Fig. 6C, D) marks the base of the *triptychoides* Zone. In contrast to the situation in the Lower Saxony Basin where *Dichotomites evolutus* Kemper disappears before the appearance of *Dichotomites triptychoides* Kemper (Kemper, 1978), the two species co-occur in the Mid-Polish Basin. Two morphological types represent intraspecific variation in *Dichotomites evolutus* Kemper – one with higher, the other with lower whorl height. Unlike in the



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sional break was observed in core material. It should be stressed, however, that no ammonites were found that would suggest the presence of the uppermost Valanginian deposits.

The first **Hauterivian** ammonite zone is the *radiatus* Zone. It is documented by the appearance of *Leopoldia leopoldi* (d'Orbigny) (Fig. 7D, E) in the core material from Łowicz IG 1, at depth of 524.9 m. These strata have hitherto been included into the Upper Valanginian (Marek, 1986). The state of preservation of the specimens from the Upper Valanginian, hitherto described as *Leopoldia* sp. (Marek, 1969), does not allow in the present author's opinion for their generic determination. The higher Lower Hauterivian zones, included in the so-called "Beds with *Endemoceras*", are documented by the following species: *Endemoceras noricum* (Roemer), *Endemoceras* aff. *enode* Thiermann, and *Endemoceras* cf. *amblygonium* (Neumayer & Uhlig) (Raczyńska, 1979; Marek & Rajska, 1997), relatively rare in comparison with the occurrences of *Dichotomites*. Their good preservation allowed Raczyńska (1979) to determine the specimens correctly. The *noricum* and *amblygonium* Zones, based on them, are suggested in this paper (Fig. 32).

The Upper Hauterivian strata are documented by the species *Simbirskites* (*Craspedodiscus*) cf. *gottschei* (Koenen) and *Simbirskites* (*Craspedodiscus*) sp., that were found in core material from Żychlin IG 1 (Raczyńska, 1979). The sediments including them were attributed to the "Beds with *Simbirskites*" (Marek & Rajska, 1997). A well-preserved ammonite *Simbirskites gottschei* (Koenen) (determination by L. Karczewski and R. Marcinowski) was found in core material from Korabiewice PIG 1, though, regrettably, the specimen is lost. The *gottschei* Zone (Fig. 32) was proposed basing on the findings of *Simbirskites gottschei* (Koenen).

The **Barremian** and **Aptian** deposits, hitherto considered as quite poor in macrofauna and treated jointly, contain incompletely preserved, scarce ammonites. A fragment of ammonite *Deshayesites* (see: Fig. 7F – *Deshayesites* sp.) was found in the core from Białobrzegi IG 1 (at the depth 925.9 m), indicating its Early Aptian age. This specimen was interpreted hitherto as *Endemoceras* sp. and attributed to the Lower Hauterivian (Marek, 1977b). Other ammonite fragments are also known from the sedimentary successions described as Barremian–Aptian (Fig. 7A–C); their age was suggested to be Aptian (Raczyńska, 1979). These findings indicate that the sedimentary basin in the area of Poland was of an open marine character.

OSTRACOD BIOSTRATIGRAPHY

The analysis of the ostracod assemblages, that have been found in well cores from central and south-eastern Poland, allowed precisely defining and, in some cases, revising the biostratigraphy of the Lower Cretaceous sedimentary series. This concerns especially the older Berriasian deposits in the "Purbeckian facies". The biostratigraphic analysis of the ostracod assemblages led to identify six ostracod zones in the Berriasian and the Valanginian strata. In many cases, they are confirmed by the results of calcareous nannoplankton analyses and correlated with the ammonite zones (Fig. 32). The ostracod zones accepted in the present study were established by Anderson (1985) in the Berriasian of England (in Purbeckian facies), and by Kubiatowicz (1983) in the Valanginian of central Poland.

Stratigraphy of the Berriasian sedimentary series in the Warsaw Trough was mainly based on distribution and appearance of new species of the genus *Cypridea*. Up to now, in sediments of the "Purbeckian facies" in Poland, six local ostracod zones were recognized and labelled as zones: F, E, D, C, B, and A (Bielecka & Sztejn, 1966). The boundary between the Jurassic and Cretaceous systems was placed between the zones B and A (Marek *et al.*, 1989; Sztejn, 1991, 1997). In this paper, the sedimentary series with ostracod assemblages of the zones E through B, hitherto included into the Upper Tithonian (Marek *et al.*, 1989), is assumed to be of Berriasian age. This series includes the upper part of the Kcynia Formation, developed as carbonate-sulphate (Wieniec Member) and marly-carbonate sediments (Skotniki Member). The biostratigraphic boundary between the Tithonian and the Berriasian stages is largely equivalent to a sequence boundary and equates with the base of carbonate-sulphate deposit of the Wieniec Member. The taxonomic composition of the ostracod assemblages in the studied material enabled correlation of the ostracod zones established in Poland with those of the Purbeckian series in England. This correlation is sometimes difficult because of the different nature of the ostracod fauna and due to lithological discontinuities, as well as to limited coring of the studied wells. The recently established correlation of the Purbeckian deposits of England with the standard Berriasian section in the Tethyan Province (Hoedemaeker, 2002) improved the reliability of the stratigraphic zonations of these sedimentary series. The sedimentary series in the Purbeckian of England, containing ostracods of the *Cypridea dunkeri* Zone, has been correlated with the ammonite *jacobi*/*grandis* Zone of the Lower Berriasian. The *Cypridea granulosa* Zone is equivalent to the Middle Berriasian *occitanica* Zone, while the sediments bearing ostracods of the *Cypridea vidrana* and *Cypridea setina* zones have been correlated with the Upper Berriasian *boissieri* Zone.

The **Berriasian** sediments were documented by ostracod fauna in central Poland (wells: Gostynin IG 1, Łowicz IG 1, and Żychlin IG 3), at the Wąwał outcrop, and in south-eastern Poland, in the Carpathian Foredeep (wells: Zagorzyce 7, Wiewiórka 4) (Fig. 1). The English ostracod zone *Cypridea dunkeri* was identified in the Lower Berriasian deposits from the Warsaw Trough. This Zone can be correlated with the Polish local ostracod zones E, D, and C *sensu* Bielecka and Sztejn (1966) (Fig. 32). The same species occur both in the Purbeckian of Poland and England, such as: *Cypridea inversa* Martin, *C. tumescens praecursor* Oertli, *C. peltoides peltoides* Anderson (Fig. 14F, G). The ostracodes mentioned above and the others species of genera: *Cypridea*, *Klieana*, *Rhinocypris*, *Darwinula*, *Scarbiculocypris*, and *Damonella* (*Damonella* sp.; Fig. 14K) were found in cores from Gostynin IG 1 (Fig. 8, samples 2, 3) and from Żychlin IG 3 wells (Fig. 9, samples 1–4). Berriasian age of sediments was also recognized on the base of the ostracod assemblages, studied in the southern part of the Carpathian Foredeep, near Dębica (wells Zagorzyce 7 and Wiewiórka 4). Detailed lithofacies analysis of the Jurassic–Cretaceous

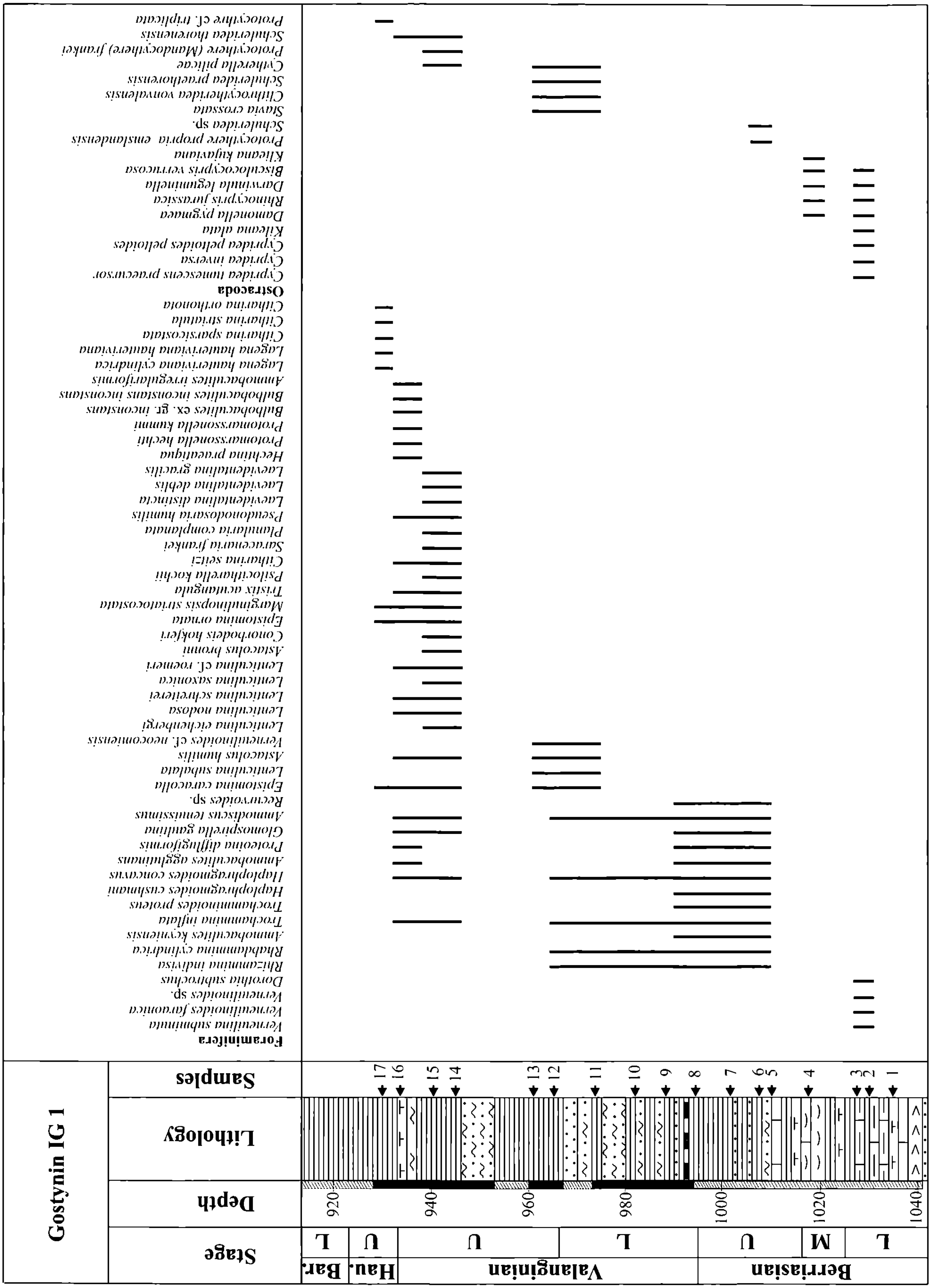


Fig. 8. Distribution chart of the foraminifers and ostracodes in the Lower Cretaceous deposits of the Gostynin IG-1; for lithological description – see Fig. 2

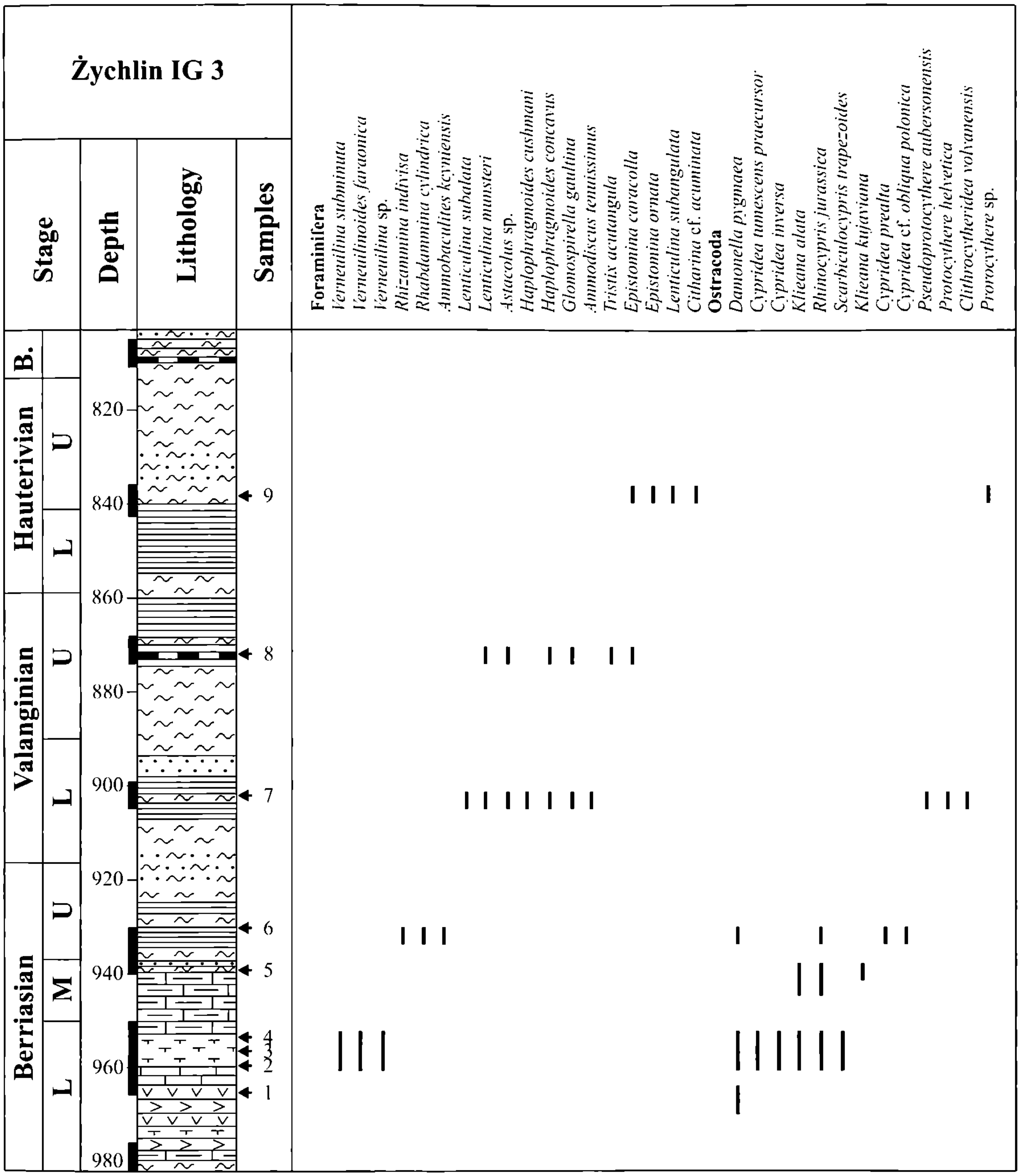


Fig. 9. Distribution chart of the foraminifers and ostracodes in the Lower Cretaceous deposits of the Żychlin IG-3; for lithological description – see Fig. 2

boundary strata in the basement of the Carpathians between Rzeszów and Dębica are available (Zdanowski *et al.*, 2001; Maksym *et al.*, 2001) to indicate that the Berriasian in the Zagorzyce 7 represents part of the Ropczyce Series (the lower calcareous-dolomitic member and the higher calcareous-marly member). A set of deposits in the Wiewiórka 4 section is lithologically similar to that from Zagorzyce 7 (Zdanowski, 2001; Zdanowski & Gregosiewicz, 2001). The Berriasian age of deposits was documented basing on microfossils in the cored sections from Wiewiórka 4 (Fig. 10, sample 1). The presence of ostracods *Cypridea tumescens tumescens* (Anderson) (Fig. 14H), *Klieana alata* Martin, and *Rhinocypris jurassica* (Martin) (Fig. 14L), characteristic of the English *Cypridea dunkeri* Zone, in the deposits of the Ropczyce Series allowed to including these strata in the Lower Berriasian. The ostracod assemblage may be also correlated with that one from the Lower Berriasian in the Jura Mountains at the French-Swiss border (Detraz & Mojon, 1989). In the Lower Berriasian from Zagorzyce 7, only fragments of charophytes (Fig. 15J) were found (Fig.11, samples: 1, 2).

In the Middle Berriasian of the Warsaw Trough, developed in Purbeckian facies, the *Cypridea granulosa* Zone was distinguished. The appearance of the index species *Klieana kujaviana* Bielecka & Sztejn (Fig. 14J) marks the ostracod zone B *sensu* Bielecka and Sztejn (1966). In this paper, the Zone B of Bielecka and Sztejn was correlated with the English *Cypridea granulosa* Zone and included to

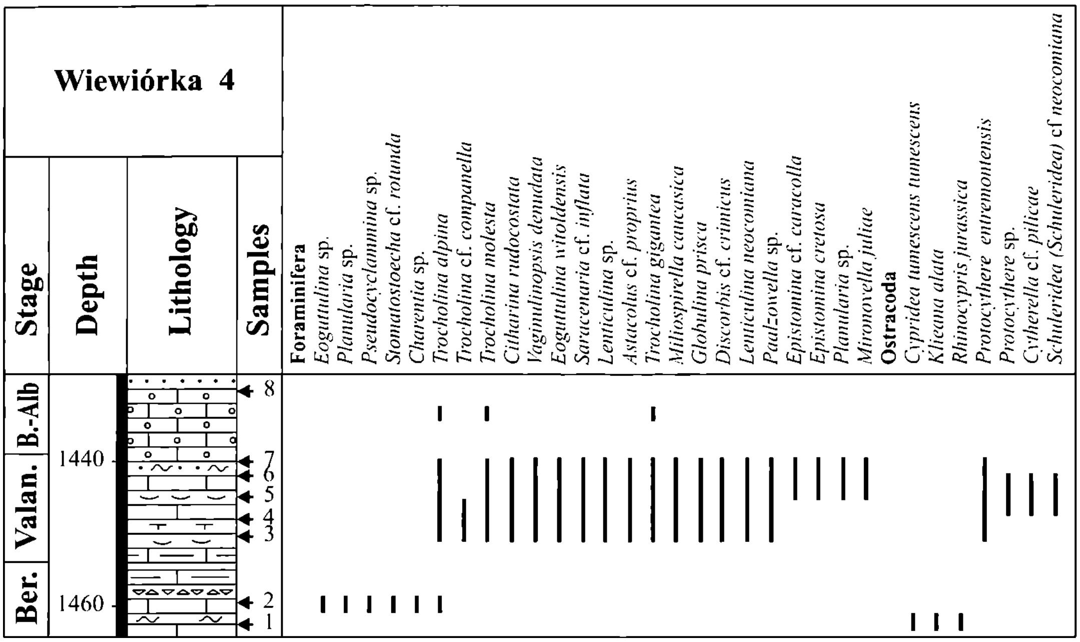


Fig. 10. Distribution chart of the foraminifers and ostracodes in the Lower Cretaceous deposits of the Wiewiórka 4: for lithological description – see Fig. 2

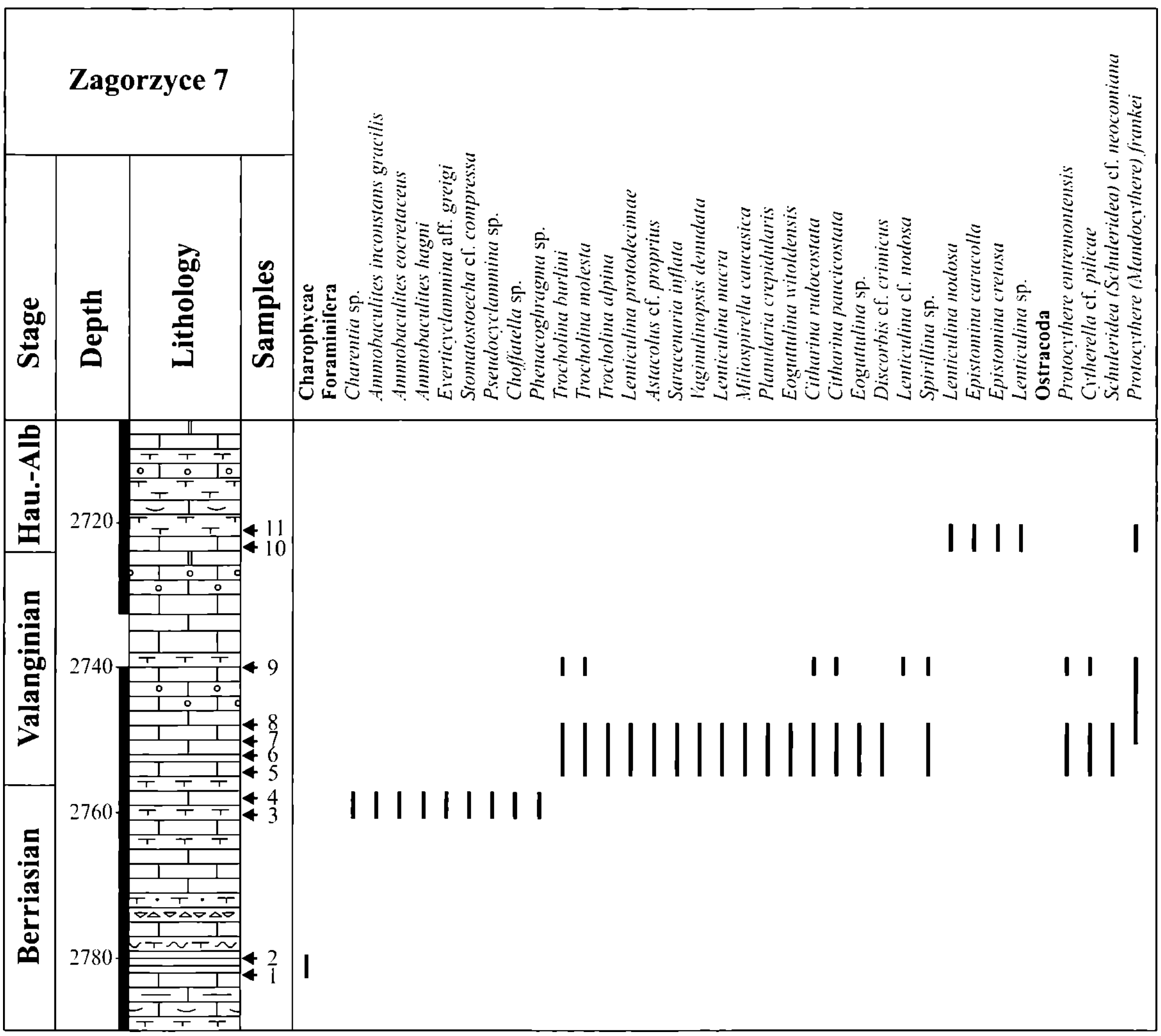


Fig. 11. Distribution chart of the foraminifers and ostracodes in the Lower Cretaceous deposits of the Zagorzyce 7; for lithological description – see Fig. 2

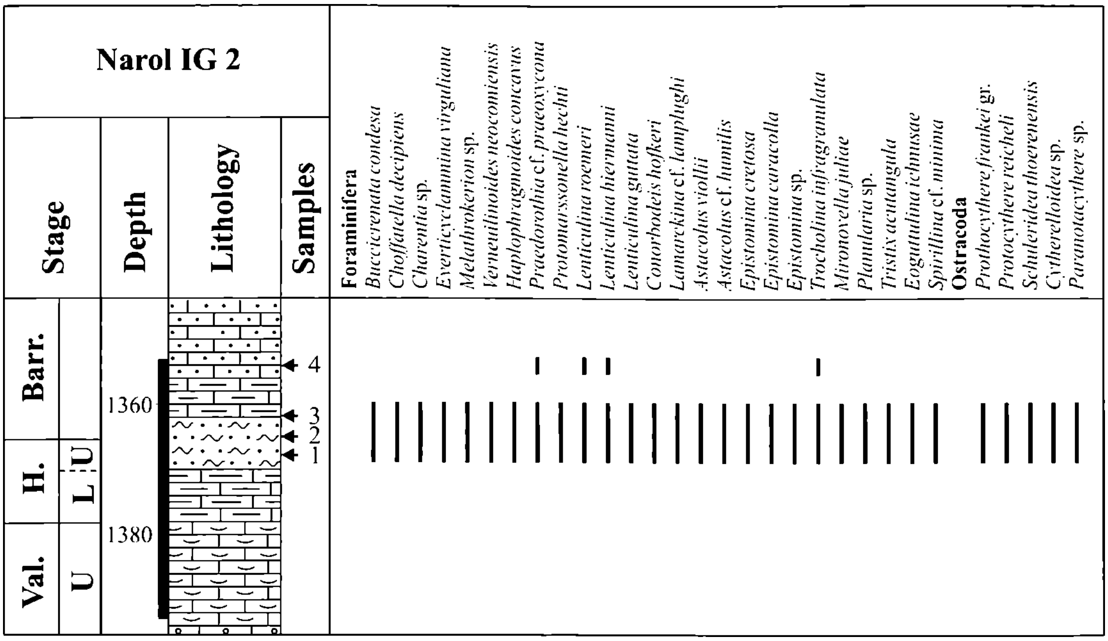


Fig. 12. Distribution chart of the foraminifers and ostracodes in the Lower Cretaceous deposits of the Narol IG-2; for lithological description – see Fig. 2

the Middle Berriasian. These parts of the Middle Berriasian sediments probably represent the marine phase of the *Cypridea granulosa* Zone that characterized the "Cinder Beds" in the Purbeckian of England. The zonal markers of Zone B and the other species of the genera: *Rhinocypris*, *Darwinula*, and *Bisculocypris* were found in cores from Gostynin IG 1 (Fig. 8, sample 4) and from Żychlin IG 3 wells (Fig. 9, sample 5).

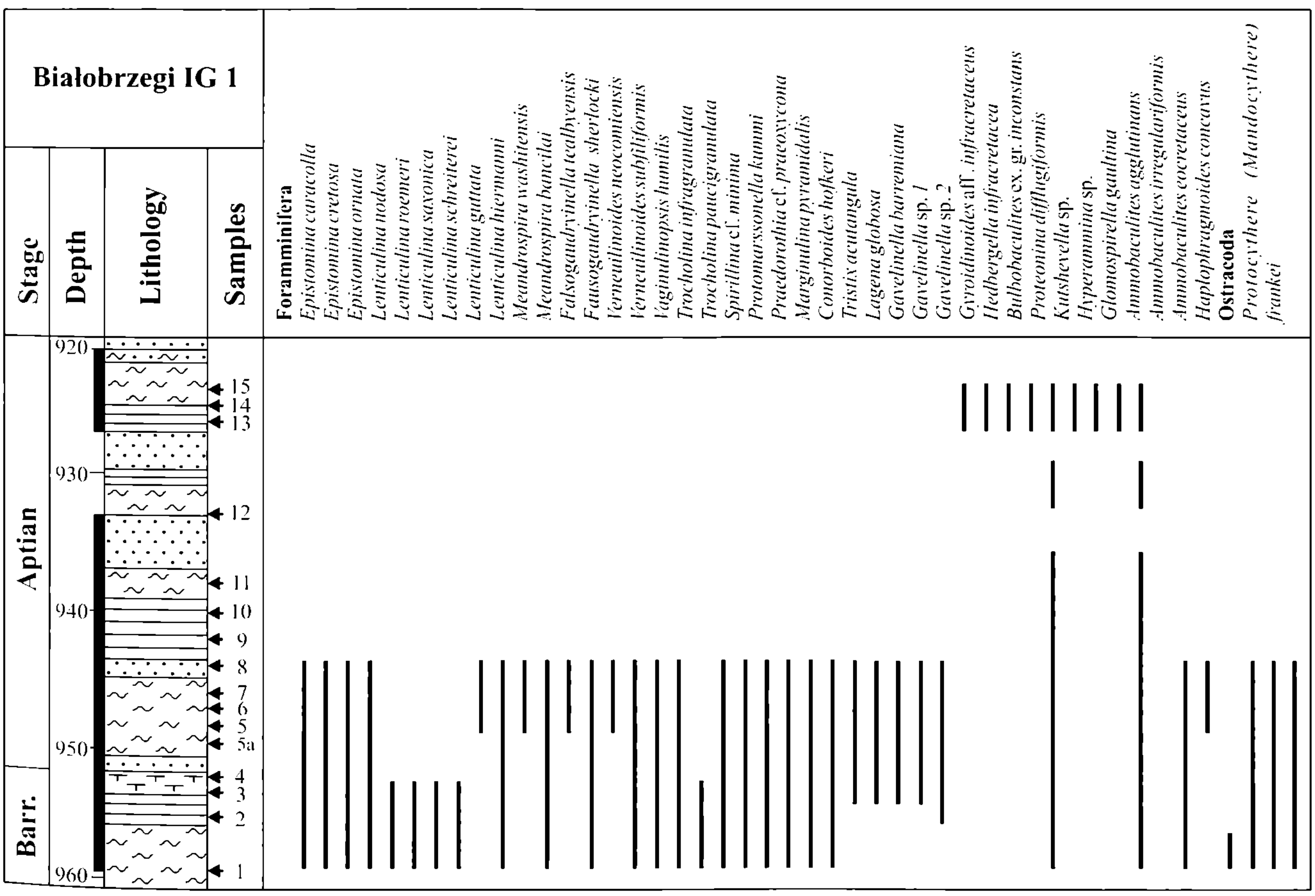
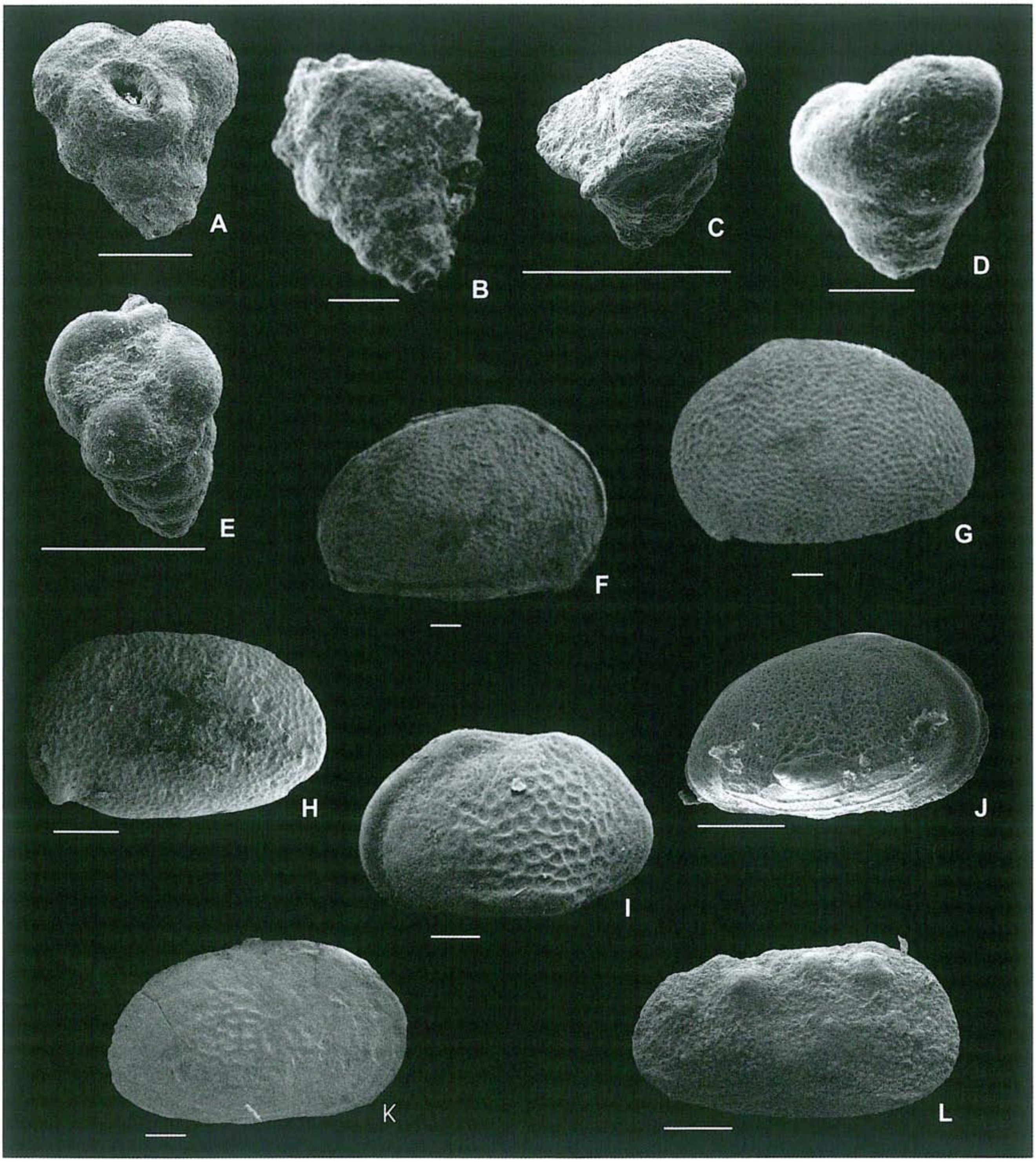


Fig. 13. Distribution chart of the foraminifers and ostracodes in the Lower Cretaceous deposits of the Białobrzegi IG-1; for lithological description – see Fig. 2



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C. obliqua polonica Sztejn). The ostracod zone described as the "assemblage with *Protocythere propria emslandensis*" was recognized in the higher part of the Upper Berriasian, developed in the Warsaw Trough as marine deposits bearing ammonites of the genus *Riasanites* and *Surites* (Marek *et al.*, 1989). It may be discerned due to the appearance of the index species *Protocythere propria emslandensis* Bartenstein & Burri, in the cored section from Gostynin IG 1 (Fig. 8, sample 6). This zone was also recorded by Kubiatowicz (1983) in the Wąwał section.

Valanginian deposits are micropalaeontologically well documented in both central and southeastern Poland. The ostracod zone *Pseudoprotocythere aubersonensis* was identified in the sediments of the Lower Valanginian and the lower part of the Upper Valanginian. This zone may be recognized on the basis of appearance of the index species *Pseudoprotocythere aubersonensis* Oertli that occurs in the succession with ammonites of the genera *Neocomites* and *Karakaschiceras*, indicative of the Lower Valanginian (Fig. 32). *Pseudoprotocythere aubersonensis* Oertli was also recorded at the Wąwał section (Kubiatowicz, 1983), and in the Paris Basin, where it ranges from the upper part of the Upper Berriasian (*boissieri* Zone) to the Upper Valanginian (*verrucosum* Zone) (Babinot *et al.*, 1985). Assemblages including the ostracod genera: *Pseudoprotocythere*, *Clithrocytheridea*, *Asciocythere*, *Cytherella*, *Shulerіdea*, and *Stavia* were found in central Poland, in cored sections from: Gostynin IG 1 (Fig. 8, samples11–13), and Żychlin IG 3 (Fig. 9, sample 7), as well as at the Wąwał section. They were also recorded in southeastern Poland, in dark-grey mudstones of the Dębica Series (Zagorzyce 7, Fig.11, samples 5–8; Wiewiórka 4, Fig. 10, samples 3–6).

The ostracod zone *Mandocythere frankei* (Kubiatowicz, 1983) was recognized within the upper part of the Upper Valanginian, basing on the appearance of the marker species *Protocythere* (*Mandocythere*) *frankei* Triebel. This Zone corresponds to the upper part of the ammonite *verrucosum* Zone and to the lower part of the *peregrinus* Zone (Hoedemaeker *et al.*, 2003) (Fig. 32). The index species *Protocythere* (*Mandocythere*) *frankei* and the ostracodes of the genera: *Cytherella*, *Schuleridea* and *Protocythere* were recognized in central Poland, in cores from Gostynin IG 1 (Fig. 8, samples 14, 15) and in some samples from the Wąwał outcrop (Tomaszów Trough). They occur in the upper part of the "Beds with *Dichotomites* and *Saynoceras*" (above the *verrucosum* Zone) up to the Hauterivian "Beds with *Endemoceras*". In southeastern Poland, the Valanginian age of the bioclastic limestones (Dębica Series) (Zdanowski *et al.*, 2001; Maksym *et al.*, 2001) is recognised on grounds of a presence of *Protocythere (Mandocythere) frankei* Triebel, and of the genera: *Schuleridea*, *Protocythere*, and *Cytherella*, in cores from Zagorzyce 7 (Fig.11, sample 9) and Wiewiórka 4 (Fig. 10, samples 5–7).

The **Hauterivian** sedimentary series in the Warsaw Trough has scarce micropalaeontological evidence because of the small amount of well core material. In the Żychlin IG 3 section, the Upper Hauterivian mudstones belonging to the *gottschei* ammonite Zone contain rare and poorly preserved ostracodes, mainly *Protocythere* sp. (Fig. 9, sample 9). The Upper Hauterivian strata were also recognized in the Gostynin IG 1 section, where *Protocythere* cf. *triplicata* (Roemer) and *Protocythere* sp. have been found (Fig. 8, sample 17). The Upper Hauterivian–Lower Barremian sediments southeastwards to the Warsaw Trough are developed in carbonate facies attributed to the Cieszanów Formation (Marek *et al.*, 1989). An assemblage of scarce ostracods, including the genera: *Prothocythere*, *Schuleridea*, *Cytherelloidea* and *Paranotacythere* was found in these sediments (Narol IG 2, Fig. 12, samples 1–7). Few ostracods were also found in the Upper Barremian–Lower Aptian deposits, dated by foraminifers and calcareous nannoplankton (Fig. 32), in core from Białobrzegi IG 1 well (Fig. 13, samples 1–7), but they are not informative stratigraphically.

FORAMINIFERAL BIOSTRATIGRAPHY

The micropaleontological analysis of the well core material from central and southeastern Poland (Figs 8–19) revealed the presence of different foraminiferal assemblages characteristic of individual stages of the Lower Cretaceous. The studied material revealed also species not earlier described from the Lower Cretaceous strata of Poland. This allows revising the biostratigraphy of some lithological series. The specific nature of foraminiferal assemblages from studied cores does not allow using previously described foraminiferal zonation schemes, neither from the Tethys area nor from the Boreal Province. Many of those schemes are only applicable to a limited regional biostratigraphy in the shallow marine boreal or tethyan basins. The first formal foraminiferal zonation scheme for the northern Tethys was established by Moullade (1984), who subdivided the Berriasian to Albian strata into fourteen zones. Unfortunately, most of the zonal markers are either absent or extremely rare in the Lower Cretaceous of the Polish Basin. In this study, biostratigraphic analysis led to establish eight foraminiferal associations and their stratigraphical succession. Only *Lenticulina eichenbergi* Zone (Moullade, 1984) was recognized in the Upper Valanginian deposits of the Warsaw Trough.

The **Berriasian** deposits have been documented by foraminiferal assemblages in central Poland (cored sections from: Gostynin IG 1, Łowicz IG 1 and Żychlin IG 3), in the southeastern Poland and in the Carpathian Foredeep (Zagorzyce 7, Wiewiórka 4) (Fig. 1). In the Warsaw Trough, the foraminiferal assemblage with *Verneuilina subminuta*, *Verneuilina angularis*, and *Verneuilinoides faraonica* has been recognized in the Lower Berriasian sediments, correlated with the *Cypridea dunkeri* ostracod Zone (Fig. 32). Foraminiferal species, such as: *Verneuilina subminuta* Gorbatchik (Fig. 14D), *Verneuilina angularis* Gorbatchik (Fig. 14B), *Verneuilinoides faraonica* (Said & Bakarat) (Fig. 14A, E) and *Dorothia subtrochus* (Bartenstein) (Fig. 14C) have not been found earlier in Poland. The species mentioned above and the others of genera: *Verneuilina* and *Verneuilinoides* have been recorded in the all studied well sections. They are especially abundant in cores from Gostynin IG 1 (Fig. 8, samples 2, 3) and from Żychlin IG 3 (Fig. 9, samples 2–4). Similar foraminiferal assemblages are known from the Berriasian deposits of the Tethyan Province in Romania (Neagu, 1997) and Crimea (Kuznetzova & Gorbatchik, 1985). The appearance of foraminifers in the "Purbeckian facies" indicates short marine ingressions preceding the Middle Berriasian transgression that probably came from the southeast.

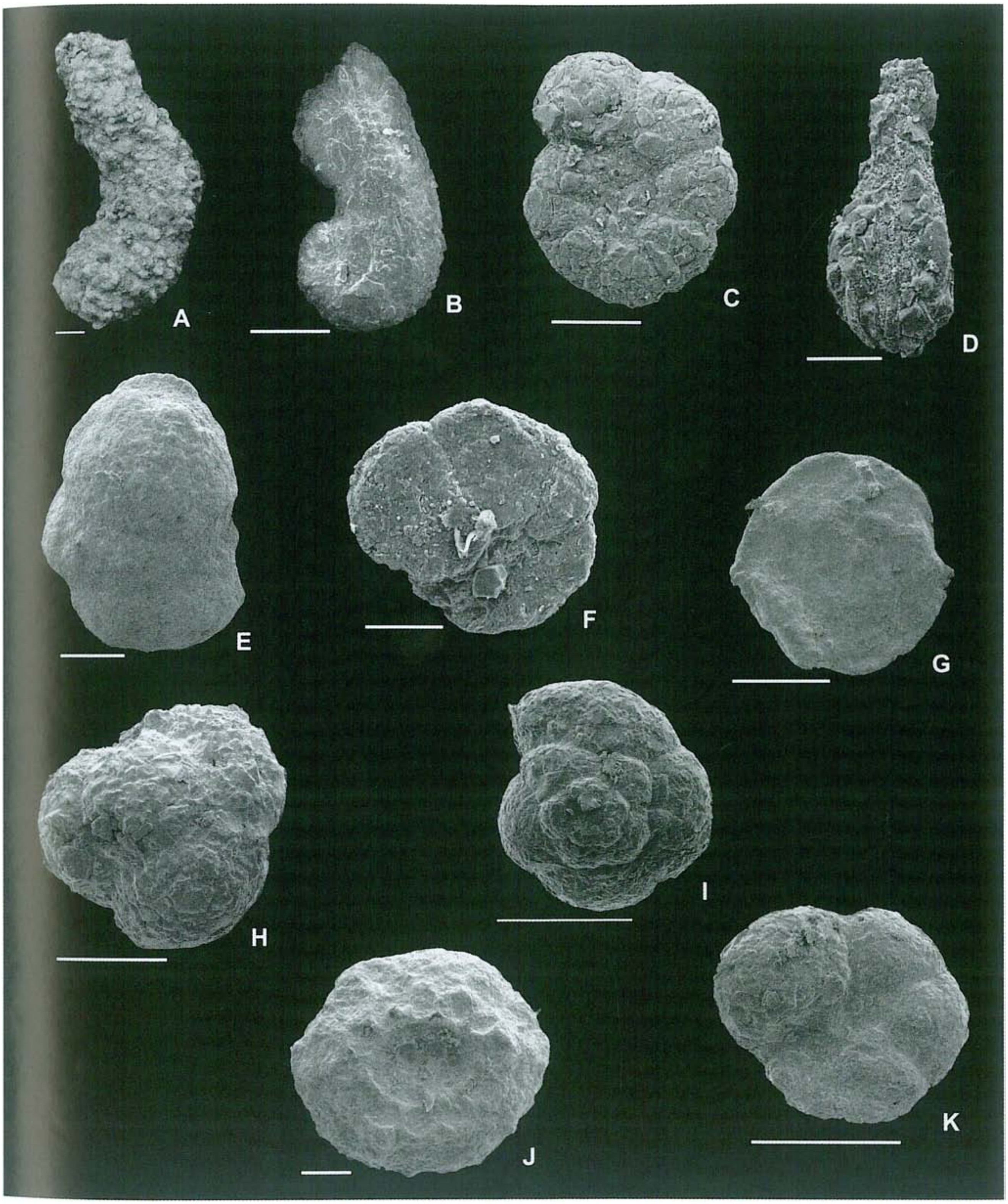
The foraminiferal assemblage with *Trochammina inflata*, *Haplophragmoides concavus*, and *Ammobaculites agglutinans* (Fig. 32) was distinguished in the higher part of the Upper Berriasian. In central Poland, this is a marine succession with ammonites of the genera *Riasanites* and *Surites* (Marek *et al.*, 1989). In the present study, this sedimentary series was correlated with the *Protocythere propia emslandesis* and the lowermost part of *Pseudoprotocythere aubersonensis* ostracod zones. The presence of abundant agglutinated foraminifers, such as: *Rhizammina indivisa* Brady (Fig. 15A), *Trochammina inflata* (Montagu) (Fig. 15I, K), *Ammobaculites kcyniensis* Sztejn (Fig. 15B), *Haplophragmoides concavus* (Chapman) (Fig. 15F), *H. cushmani* Loeblich & Tappan (Fig. 15C), *Proteoina difflugiformis* Brady (Fig. 15D), and *Glomospirella gaultina* (Bethelin) (Fig. 15G) is characteristic for these sediments. They were mostly recorded in cored section from Gostynin IG 1 (Fig. 8, samples 5–8). Similar foraminiferal assemblages are characteristic of higher Berriasian siliciclastic shelf sediments in central Poland (Sztejn, 1968, 1990). The presence of agglutinated foraminifers of family Lituolidae, with abundant *Charentia* sp. (Fig. 15E) is characteristic of the Upper Berriasian strata in the southern part of the Carpathian Foredeep, near Dębica (the upper part of the marly-carbonate member of the Ropczyce Series). This assemblage includes also calcareous foraminifers of the genera: *Trocholina*, *Eoguttulina*, and *Planularia*. Such assemblages were found in cored sections from Zagorzyce 7 (Fig. 11, samples 3, 4) and Wiewiórka 4 (Fig. 10, sample 2). Previous biostratigraphic studies of the Lower Cretaceous sediments in southeastern Poland (including the cored section from Stasiówka 1 in the Carpathian Foredeep) were limited to a few works (e.g., Geroch *et al.*, 1972). Biostratigraphic studies in the Lublin region were done by Moryc and Waśniowska (1965) and Sztejn (1996). Biostratigraphic studies of the Lower Cretaceous deposits in the Carpathian Foredeep were also undertaken by Olszewska (1999, 2001), who studied microfauna in thin sections.

In central Poland, four characteristic foraminiferal assemblages have been distinguished in the **Valanginian** sediments attributed to the ostracod zone *Pseudoprotocythere aubersonensis* (Fig. 32). Impoverishment of the foraminiferal fauna and predominance of agglutinated foraminifers was observed in the Lower Valanginian strata, assigned to the *robustum* Zone. Near the top of the Lower Valanginian, in deposits bearing abundant bivalves and ferruginous concretions, the assemblage of microfauna is impoverished and their taxonomic composition indicates shallowing of the basin. At the base of the Lower Valanginian, developed as argillaceous-mudstone facies, an assemblage of agglutinated foraminifers with *Trochammina inflata*, *Haplophragmoides concavus*, and *Ammobaculites agglutinans* has been recorded. The assemblage is similar to those from the uppermost Berriasian. The first assemblage of calcareous benthic foraminifers appeared in the beds with ammonites of the genera *Neocomites* and *Karakaschiceras*. It was named in the present study as the assemblage with *Epistomina caracolla*, *Lenticulina subalata*, and *Verneuilinoides neocomiensis*. This assemblage was recorded in cored sections from: Gostynin IG 1 (Fig. 8, samples 11–13), Łowicz IG 1, and from Żychlin IG 3 (Fig. 9, sample 7). In the upper part of the Lower Valanginian the assemblages with *Glomospirella gaultina* and *Ammodiscus tenuissimus*, and with *Epistomina caracolla* and *Lenticulina subalata* have been found. They are also characteristic for the Upper Valanginian (the lowermost part of the ammonite *verrucosum* Zone) (Fig. 32).

The Upper Valanginian deposits in central Poland contain abundant and highly diversified assemblages of foraminifers. The foraminiferal *Lenticulina eichenbergi* Zone was identified in the sediments of the uppermost part of *verrucosum* to *triptichoides* zones (Fig. 32). *Lenticulina eichenbergi* Bartenstein & Brand, which in the Tethyan Province marks the foraminiferal horizon *Lenticulina eichenbergi* (Moullade, 1984), has been accepted as the index species for this zone. The Upper Valanginian age of deposits at the Wąwał outcrop (the Tomaszów Trough) is indicated by the ammonites (Kutek *et al.*, 1989; Ploch, 2002). The more abundant foraminifers were observed in the higher part of the Wąwał section, corresponding to the *polytomus – crassus* ammonite Zone and to the lower part of the *triptychoides* Zone. These assemblages include many species of calcareous and agglutinated foraminifers, such as: *Epistomina*, *Lenticulina*, *Tristix*, *Citharina*, *Psilocitharella*, *Pseudonodosaria*, *Frondicularia* and *Conorboides* (Fig. 16H–L; Fig. 17A–D, J). The amount of agglutinated forms relative to the calcareous ones, of which numerous are only those of genus *Epistomina*, increases in the upper part of the *triptychoides* Zone. Glauconite-rich sediments in the highest part of the Wąwał section do not contain microfauna. The foraminiferal assemblage of the *Lenticulina eichenbergi* Zone was described in cored section from the Gostynin IG 1 (Fig. 8, samples 14, 15; Fig. 17E, F) in the Warsaw Trough. In central Poland, conditions in the depositional basin changed during the latest Valanginian. Sandy mudstones with admixture of ferruginous oolites were laid down, indicating a stratigraphic condensation during the maximum flooding phase.

The foraminiferal assemblage with *Hechtina praeantiqua*, *Protomarssonella kummi*, and *Protomarssonella hechti* was recognized in the uppermost part of the Upper Valanginian, in the Warsaw Trough (Fig. 32). The index species and the other genera, such as *Proteoina*, *Glomospirella*, *Ammodiscus* and *Bulbobaculites* were recognised in the cored section from the Gostynin IG 1 well (Fig. 8, sample 16) (Fig. 17G, H, I, K; Fig. 18A–D). Similar foraminiferal assemblages are characteristic for deposits assigned to the "Beds with *Dichotomites*" in the Boreal Province, e.g., in the Lower Saxony Basin (Mutterlose *et al.*, 2000; Klein & Mutterlose, 2001), though the amount of agglutinated forms is there higher than in the Polish Basin. This is certainly due to the stronger influence of the Boreal Sea in the Lower Saxony Basin.

In the area situated southeastward to the Warsaw Trough, the Valanginian deposits are developed in siliciclastic-carbonate and carbonate facies of the Dębica Series (Zdanowski *et al.*, 2001). These sediments were docu-



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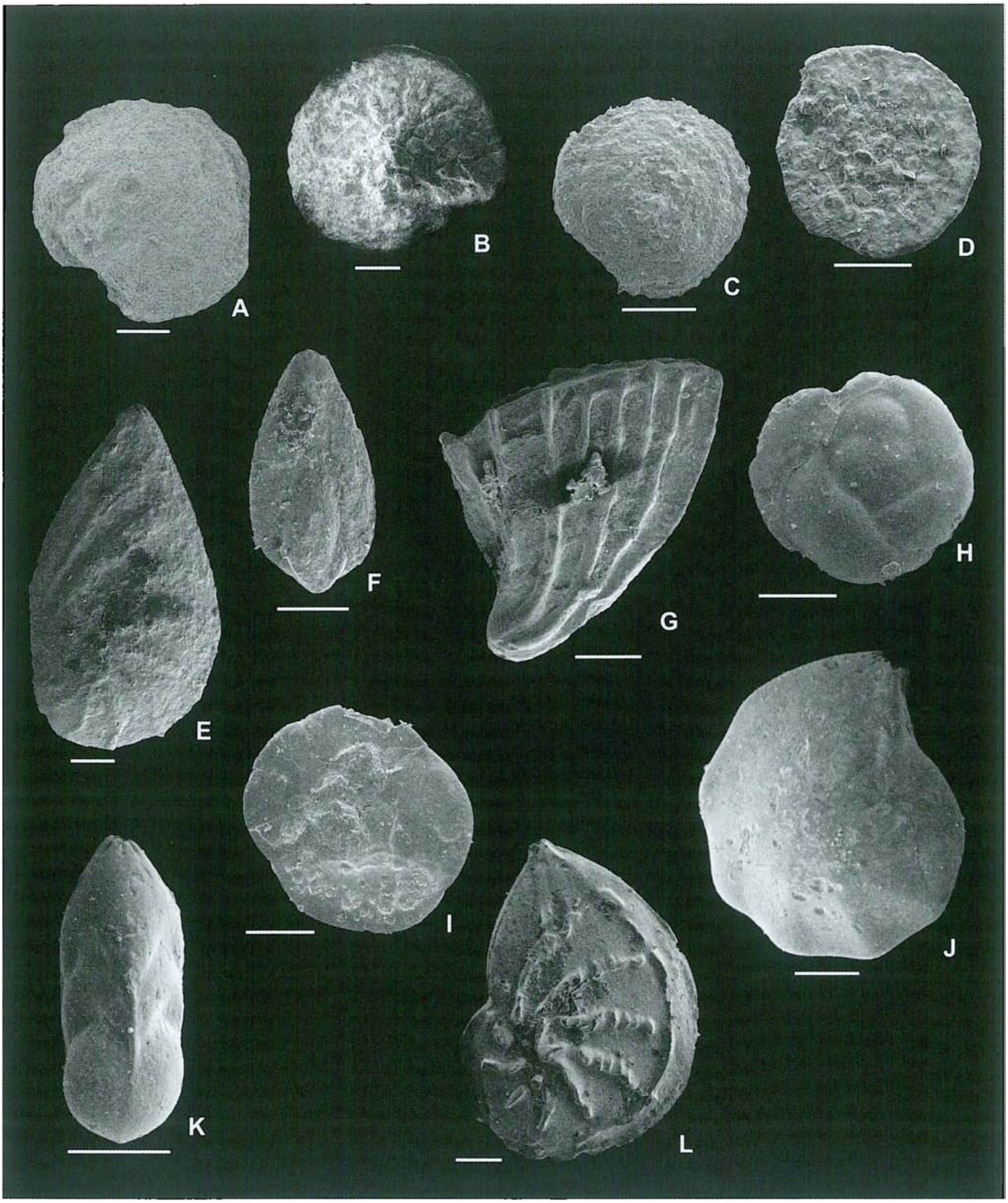

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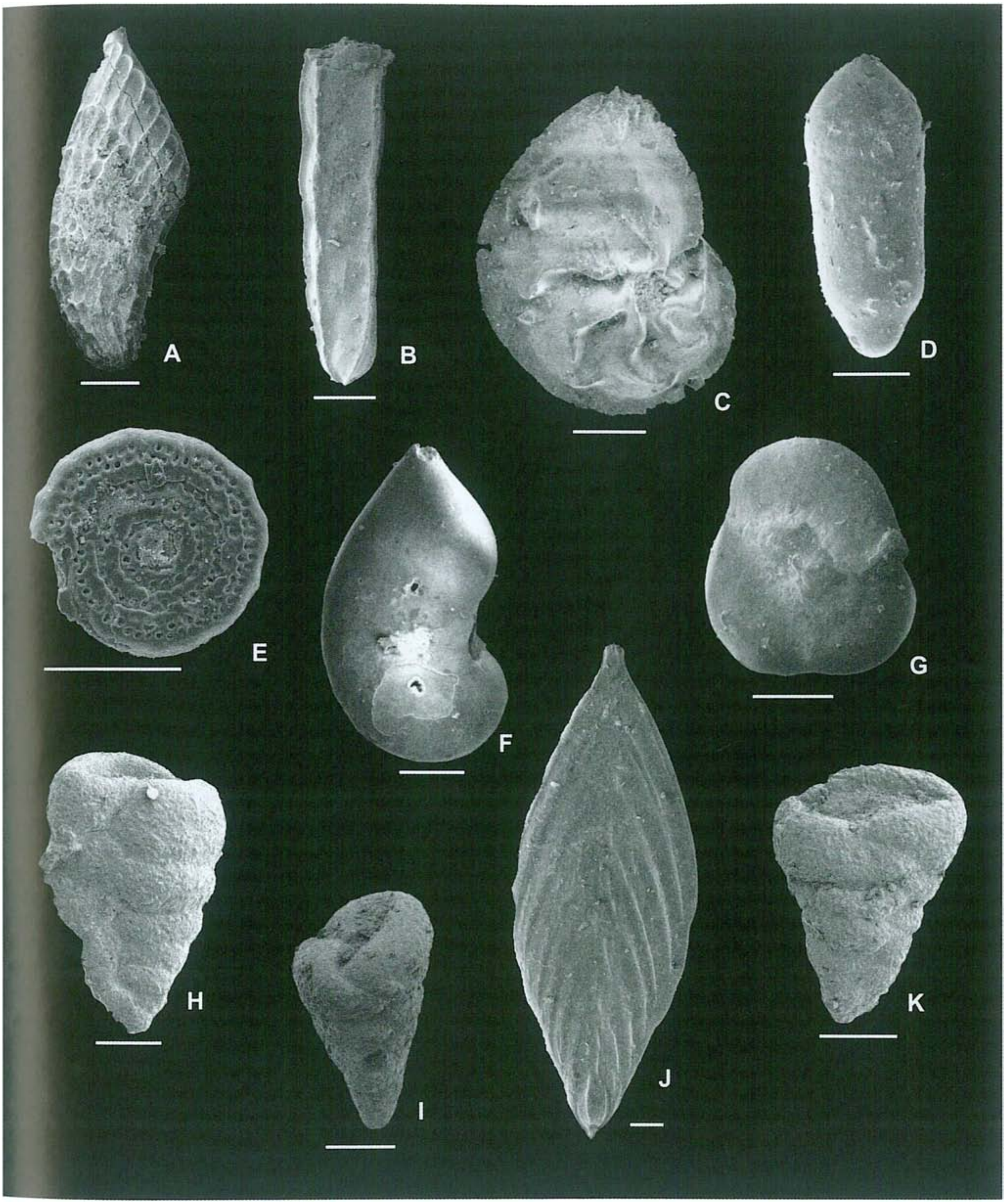

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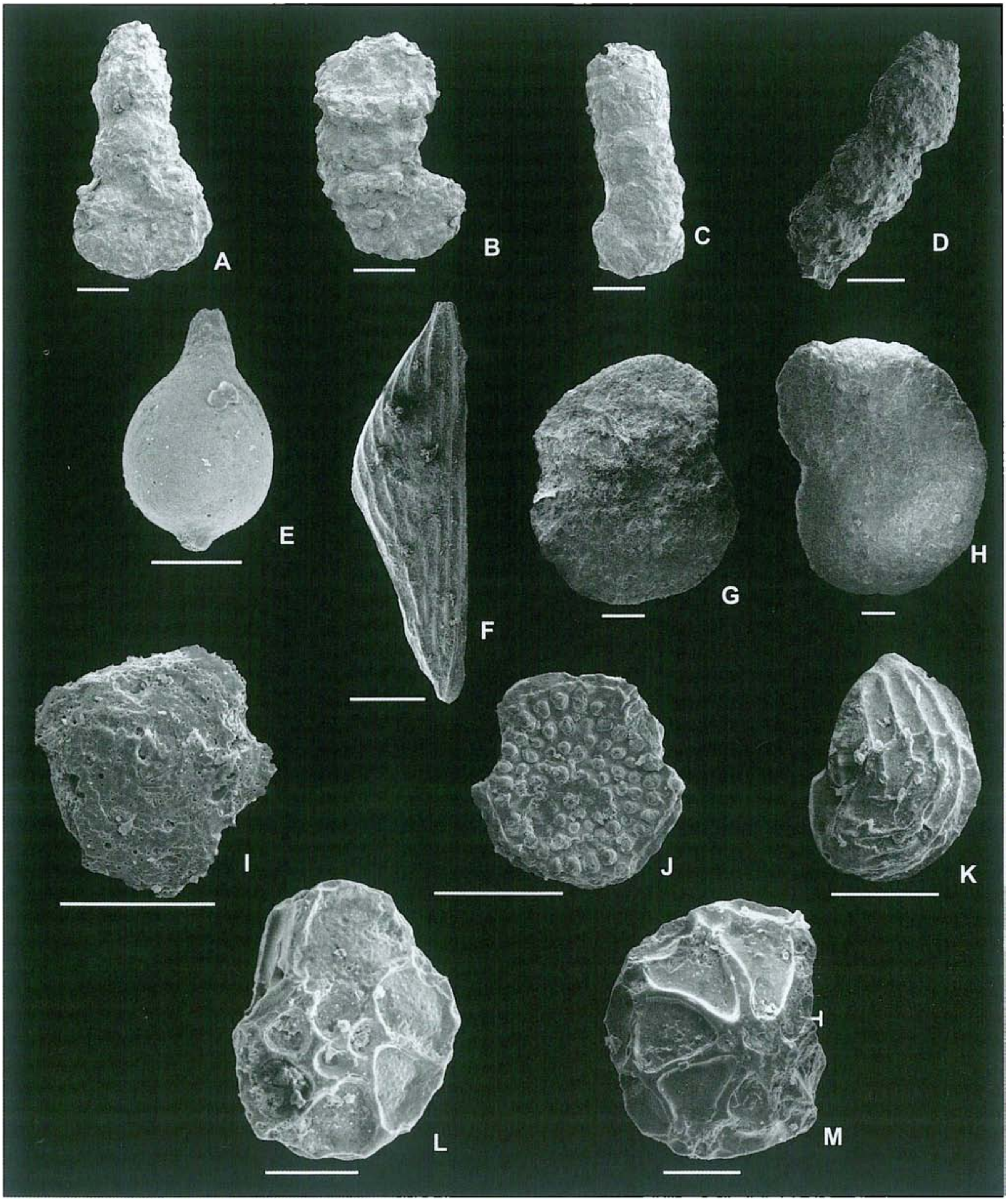

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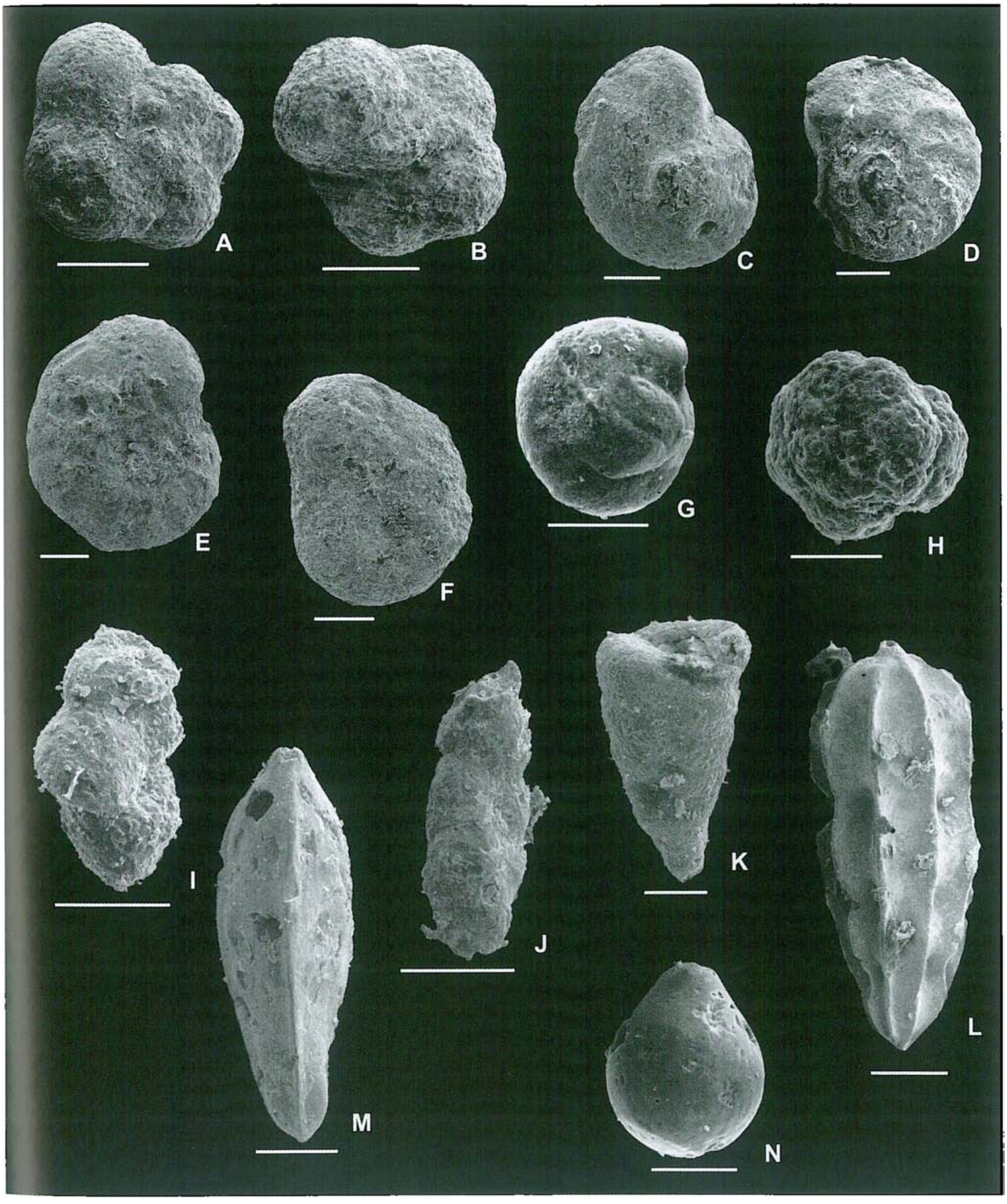

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mented by foraminiferal microfauna in the cored sections from Zagorzyce 7 and Wiewiórka 4. The Lower Valanginian carbonate deposits of the Dębica Series contain rich foraminiferal assemblages with *Trocholina*, characteristic for the carbonate facies of the northern Tethys shelf (Kuznetzova & Gorbatchik, 1985). The most numerous foraminifers in this sediment are: *Trocholina burlini* Gorbatchik (Fig. 16C, D), *T. molesta* Gorbatchik (Fig. 16A, B), *Astacolus* cf. *proprius* Kuznetzova (Fig. 16E), *Eoguttulina witoldensis* Sztejn (Fig. 16F), and *Citharina paucicostata* (Reuss) (Fig. 16G). The foraminiferal species mentioned above and the others of genera: *Trocholina*, *Lenticulina*, *Saracenaria*, *Vaginulinopsis*, *Miliospirella*, *Planularia*, *Citharina*, *Discorbis*, and *Spirillina* were found in cores from Wiewiórka 4 (Fig. 10, samples 3–7) and from Zagorzyce 7 (Fig. 11, samples 5–8). The Late Valanginian (and probably Early Hauterivian) sediments of the Dębica Series are documented by the appearance of the foraminiferal species: *Epistomina caracolla* (Roemer) and *Lenticulina nodosa* Reuss in cored sections from Zagorzyce 7 (Fig. 11, samples 9–11).

The **Hauterivian** sediments in the Warsaw Trough have scarce micropalaeontological evidence. In the Lower Hauterivian sequences of sandy mudstones and sandstones, of the *radiatus* ammonite Zone (e.g., Łowicz IG 1 section), only impoverished assemblage of lenticulinids, epistominids and agglutinated foraminifers were recovered. In the cored section from Żychlin IG 3, the Upper Hauterivian mudstones attributed to the *gottschei* ammonite Zone, contain scarce microfauna, including: *Epistomina ornata* (Roemer), *E. caracolla* (Roemer), *Lenticulina subangulata* (Reuss), and *Citharina* cf. *acuminata* (Reuss) (Fig. 9, sample 9). The Upper Hauterivian foraminiferal assemblages including: *Lagena hauteriviana cylindrica*, *Citharina orthonota*, and *C. sparsicostata* (Fig. 32) were also identified in the cored section from Gostynin IG 1. The index species were accompanied by the other species of the genera: *Lagena* (Fig. 18E), *Citharina* (Fig. 18F), *Epistomina*, and *Lamarckina* (Fig. 8, sample 17). Similar microfaunal assemblages have been described from the Upper Hauterivian and lowermost Barremian deposits in the Boreal Province, in northwestern Germany and England (Bartenstein *et al.*, 1991).

Southeastwards from the Warsaw Trough, carbonate facies are attributed to the Cieszanów Formation of the Hauterivian age (e.g., Narol IG 1, Narol IG 2; Figs 39, 42) (Marek *et al.*, 1997). The foraminiferal assemblages recovered in these deposits indicate the Late Hauterivian – earliest Barremian age (Fig. 12, samples 1–4). It is suggested by the presence of: *Buccicrenata condesa* Dulub (Fig. 18G, H), *Choffatella decipiens* Schlumberger, *Lenticulina hiermanni* Bettenstead, *Trocholina paucigranulata* Moullade, and *Praedorothia* cf. *praeoxycona*, that are reported most frequently from the Upper Hauterivian through Lower Aptian deposits of the Boreal and Tethyan Realms (Holbourn & Kamiński, 1997). These deposits were previously attributed to the Upper Valanginian and Lower Hauterivian (Marek *et al.*, 1989; Sztejn, 1996).

Sedimentary series of the higher part of Lower Cretaceous (Barremian, Aptian) in the Warsaw Trough, including mainly coarse-grained siliciclastic deposits, makes a part of the Mogilno Formation (Marek *et al.*, 1989). There were no microfossils found in these series (Gostynin IG 1, Żychlin IG 3, Łowicz IG 1). In southeastern Poland, the siliciclastic facies are replaced by clastic-carbonate and carbonate deposits. Finding of the **Late Barremian–Early Aptian** microfauna, described in this paper as the assemblage with *Gavelinella barremiana* and *Hedbergella infracretacea* (Fig. 32), makes an important part of this study. The assemblages were recorded in deposits of the Białobrzegi Formation, in the cored section from Białobrzegi IG 1 (Fig. 13, samples 2–8). These sediments contain a very rich assemblage of microfauna with the most important: *Gavelinella barremiana* Bettenstaedt (Fig. 19C, D), *Gyroidinoides* aff. *infracretaceus* Morozova, *Hedbergella infracretacea* (Glaessner) (Fig. 19A, B), *Meandrospira washitensis* Loeblich & Tappan (Fig. 19G), *M. bancilai* Neagu (Fig. 19H), *Praedorothia* cf. *praeoxycona* (Moullade), and *Falsogaudryinella scherlocki* Bettenstaedt (Fig. 19I). They are also accompanied by numerous foraminifers of the genera: *Epistomina* (Fig. 18L, M), *Lagena* (Fig. 19N), *Lenticulina* (Fig. 18K), *Marginulina* (Fig. 19L), *Protomarssonella*, *Spirillina*, *Tristix* (Fig. 19M), *Trocholina* (Fig. 18I, J), and *Verneuilinoides* (Fig. 19J). The species described in the cores from Białobrzegi IG 1 are known from the Barremian and Aptian strata. The foraminiferal genus *Gyroidinoides* was found to occur beginning from the Aptian (Holbourn & Kamiński, 1997; Riegraf & Luterbacher, 1989; Moullade, 1984). Its presence suggests that the age of the Białobrzegi Formation is Late Barremian through Early Aptian, rather than Late Valanginian through Hauterivian, as it was hitherto assumed (Marek *et al.*, 1989).

NANNOFOSSIL BIOSTRATIGRAPHY

Some Lower Cretaceous marine successions within central and southeastern Poland contain abundant and well preserved assemblages of calcareous nannoplankton. However, up to now, nannofossils have not been used as a stratigraphic tool in reference to these sedimentary series, except one section from the Warsaw Trough. The analysis of nannofloral assemblages, found in some samples from cored section from Korabiewice PIG 1 (Fig. 37), has allowed to constrain a stratigraphic position of the dark-grey and poorly fossiliferous, marly shales (Gaździcka, 1993). Based on nannofossil data, this succession was attributed to the Upper Hauterivian, corresponding to the ammonite *gottschei* Zone. For the purpose of this study nannofossil assemblages of cored sections from twelve wells in central and southeastern Poland were examined.

To date, many proposals of nannoplankton zonation schemes have been presented for the Lower Cretaceous (e.g., Roth, 1973; Thierstein, 1976; Taylor, 1982; Jakubowski, 1987). The zonation established by Sissingh (1977) and modified by Perch-Nielsen (1979, 1985), known as a standard nannofossil zonation, is the most commonly used one for the Lower Cretaceous strata. On the other hand, the stratigraphic zonation scheme for the Lower Cretaceous of the Boreal Realm is the most refined one (Bown *et al.*, 1999). The specific nature of nannofossil assemblages from the Lower Cretaceous of the Polish Lowlands allows for exclusive use of the zonation shemes neither from Tethys nor from the Boreal Province. The nannofossil assemblages include both tethyan and the boreal taxa, and the proportion of both palaeobiogeographic elements changes in the studied sections. But there are still neither continual data of the tethyan nannofossil succession nor of the boreal one. This unique character of nannoflora results from the palaeogeographic position of sedimentary basins, situated between these two major provinces. However, a taxonomic composition of the nannofossil assemblages shows the closest affinities to those from the Lower Saxony Basin (see Mutterlose, 1991). A content of the tethyan species is still higher than in coeval deposits from Germany. Also lack or scarcity of the boreal taxa in some stratigraphic intervals is symptomatic. Nevertheless, the zonation scheme established in German Basin by Mutterlose (1991, 1992) is the most useful for stratigraphy of the Lower Cretaceous strata from the Polish Lowlands, and it has been adapted with some modifications for the purpose of this study (Fig. 20). It also enables a correlation of depositional sequences from these two neighbouring sedimentary basins.

The succession of nannofossil assemblages observed in the studied sections has allowed for distinguishing of biostratigraphic zones or only their lower or upper boundaries, that correspond to the first (FO) or to the last occurrences (LO) of the marker species. This results from both uncontinuous coring and sedimentary gaps in the studied sections. Differences between the successions of nannofossil taxa from the Polish and the Lower Saxony basins have been observed mainly within the following intervals: 1) the Berriasian–Lower Valanginian, for which no nannoplankton zones have been distinguished in the German Basin, 2) the Upper Hauterivian, and 3) the Lower Aptian. The Late Berriasian assemblage includes some tethyan as well as cosmopolitan taxa, what has enabled identification of Thierstein's, *Retacapsa angustiforata* Zone. Nannofloral assemblage recorded in the Upper Hauterivian consists, in turn, mainly of the boreal taxa. In the present study, the first Upper Hauterivian zone is established using the FO of *Perissocyclus plethotretus* (Wind et Čepek), as indicative of its lower boundary. In the Lower Aptian, the Mediterranean species were dominant again and thus they were used as zonal markers. The nannofossil zonation scheme, proposed for the Lower Cretaceous in Polish Lowlands includes thirteen zones. They are labelled PN (from: *Polish Nannoplankton Zones*) and given successive numbers (Figs 20–25). The zonation scheme is summarized in Fig. 20. Selected species of coccoliths, characteristic of the early Cretaceous assemblages are shown in Figs 26–31.

Proposed zonation scheme

PN 1 *Retacapsa angustiforata*

Definition: Interval between the FO of *Retacapsa angustiforata* and the FO of *Zeugrhabdotus diplogrammus*.
Author: Thierstein (1971) emend. Gaździcka (this paper).
Stratigraphic range: Upper Berriasian and the lowermost Valanginian; the zone corresponds to the tethyan ammonite *boissieri* Zone, and possibly to the lowermost part of the Lower Valanginian *petransiens* Zone.
Remarks: In the Tethyan Realm, *R. angustiforata* appears in the lowermost Middle Berriasian, corresponding to lower part of the ammonite *occitanica* Zone, or even in the Lower Berriasian (Bergen, 1994). In the Boreal Realm, it has been recorded only in the Upper Ryazanian, corresponding to the uppermost part of the Middle and to the Upper Berriasian (Bown *et al.*, 1999). The differrence may be caused by the lack of nannofossil-bearing facies, older than the Upper Berriasian, or a regional unconformity between the Upper Jurassic and the Lower Cretaceous in the North Sea. In the Polish Lowlands, *R. angustiforata* (Fig. 29C) appears in the lowermost part of the Upper Berriasian. It has been recorded together with the first Berriasian ammonite assemblages. These events are also associated by a change of microfaunal assemblages, and they are correlated with the lower boundary of the ostracod zone *C. vidrana* (Fig. 32). PN 1 has been recognised in the cored sections from Gostynin IG 1 (Fig. 22) and Żychlin IG 3, in sedimentary succession distinguished as the Rogoźno Formation.

PN 2 *Zeugrhabdotus diplogrammus*

Definition: Interval between the FO of *Zeugrhabdotus diplogrammus* and the appearance of poorly differentiated assemblages, comprising mainly *Watznaueria barnesae*.
Author: Gaździcka (this paper).
Stratigraphic range: Lowermost Valanginian, corresponding to the lower part of the tethyan ammonite *petransiens* Zone and to the boreal zones *robustum* and *heteropleurum*.
Remarks: In the studied sequences, *Z. diplogrammus* appears together with tethyan ammonites of the genus *Neocomites* and *Neohoploceras* that are characteristic for the lowermost Valanginian (cf. Fig. 2 and Fig. 21). This is probably the oldest known occurrence of this species. According to Bown *et al.* (1999), the FO of *Z. diplogrammus* in the Boreal Province is in the uppermost part of the Lower Valanginian. The appearance of this species in Poland, in the *petransiens* Zone, indicates its tethyan provenance. *Zeugrhabdotus diplogrammus* is accompanied by other tethyan coccoliths: *Cyclagelosphaera margerelii* (Fig. 26G), *Micrantholithus obtusus* (Fig. 26K) and *Watznaueria barnesae* (Fig. 26I). The nannofossil assemblages in PN 2 are also more taxonomically diversified than the Berriasian ones. The *Z. diplogrammus* Zone, comprising the lowermost Lower Valanginian, has been recognised in cored section from Łowicz IG 1, in the uppermost part of the Rogoźno Formation (Fig. 21). The stratigraphic position of this formation has hitherto been determined as the "Ryazanian".

PN 3 *Watznaueria barnesae*

Definition: Interval between the appearances of a poorly differentiated assemblages, dominated by coccoliths *Watznaueria barnesae* and the FO of *Eiffellithus striatus*.
Author: Gaździcka (this paper).
Stratigraphic range: Upper part of the Lower Valanginian,

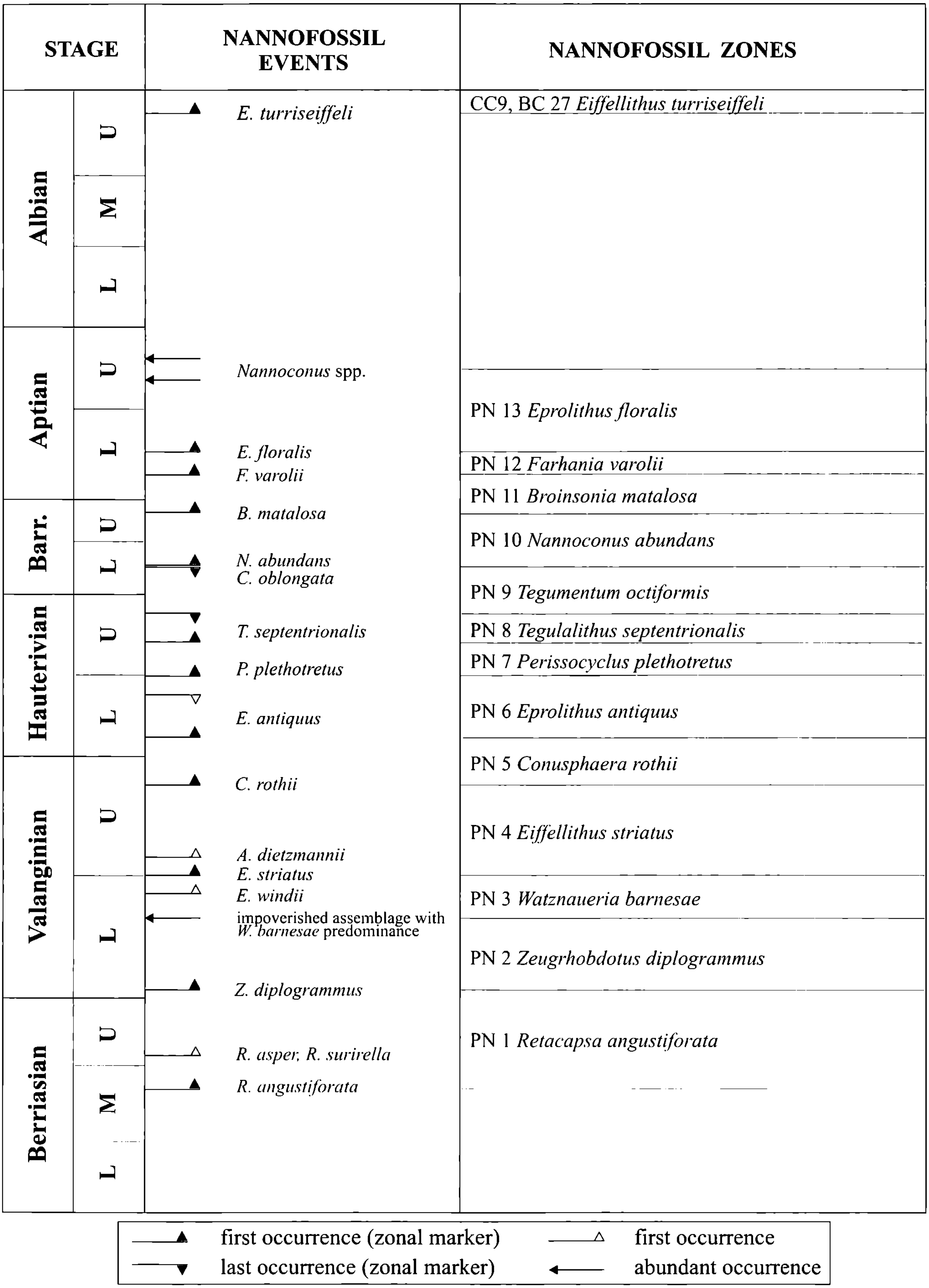


Fig. 20. Nannoplankton events and biostratigraphy of the Lower Cretaceous in central and SE Poland

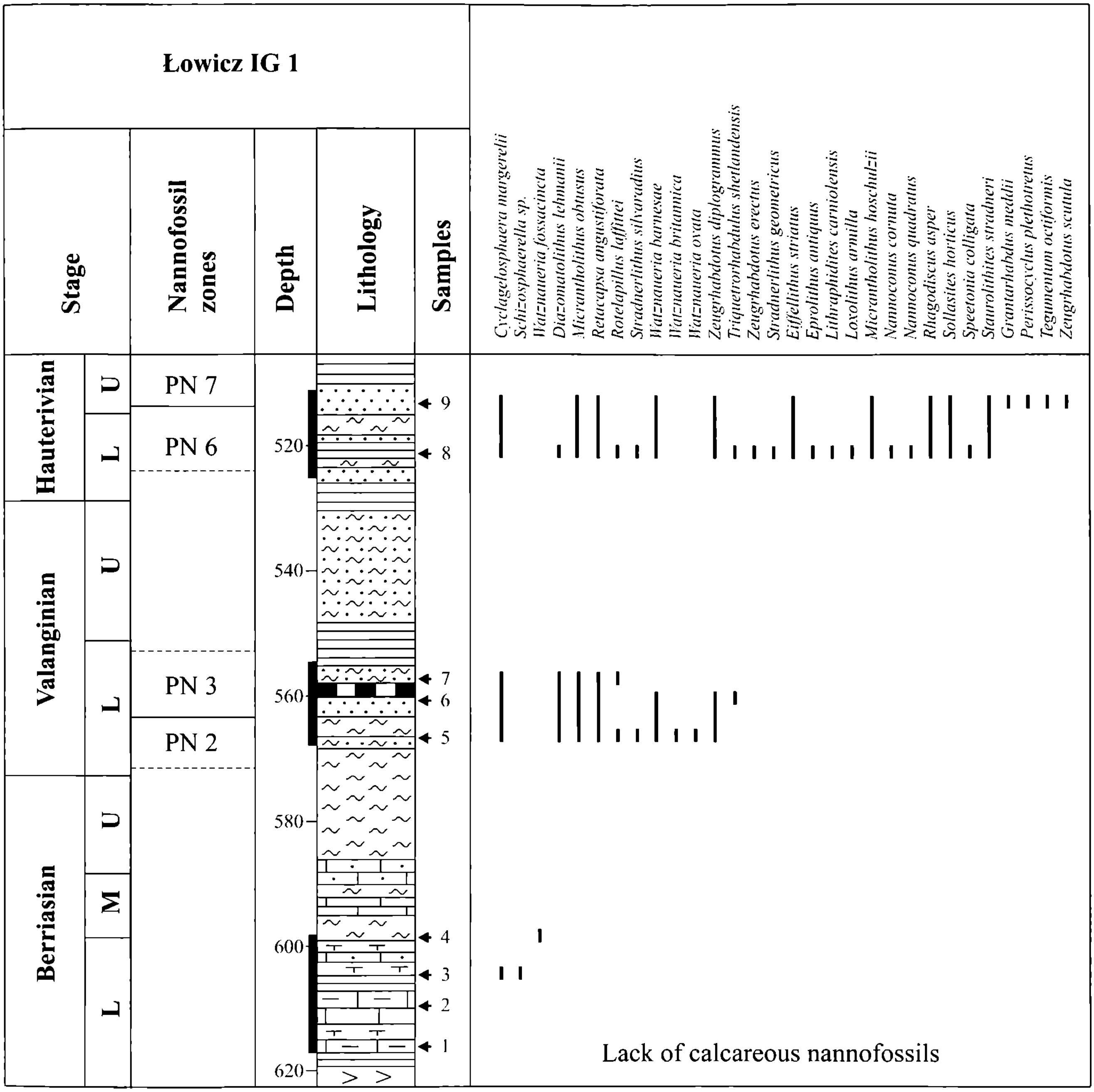


Fig. 21. Distribution chart of calcareous nannofossils in the Lower Cretaceous deposits of the Łowicz IG 1; for lithological description – see Fig. 2

corresponding to the uppermost part of tethyan *petransiens* Zone and to the *campylotoxus* Zone. It may be also correlated with the boreal *Polyptychites* spp. Zone.

Remarks: A gradual impoverishment of calcareous nannoplankton assemblages in respect of taxonomical diversification is noticeable since the upper part of the ammonite *petransiens* Zone, together with the appearance of the first boreal ammonites. Sedimentary sequences with ammonites of the genus *Polyptychites* ("Beds with *Polyptychites*"; Marek, 1997) contain nearly monospecific coccolith assemblages with predominant *Watznaueria barnesae*. The PN 3 *Watznaueria barnesae* Zone, corresponding to the upper part of the Lower Valanginian, was recognized both in the sections from the Warsaw Trough (Łowicz IG 1, Fig. 21; Gostynin IG 1, Fig. 22; and Żychlin IG 3), and from the Tomaszów Trough (Wąwał clay-pit). It corresponds to the lower part of the Bodzanów Formation.

PN 4 *Eiffellithus striatus*

Definition: Interval between the FO of *Eiffellithus striatus* and the FO of *Conusphaera rothii*.

Author: Mutterlose (1991).

Stratigraphic range: Upper Valanginian, interval corresponding to the boreal ammonite zone *Dichotomites* spp., comprising five zones established in the Lower Saxony Basin: *hollwedensis*, *polytomus*, *crassus*, *triptychoides*, and *bidichotomites* (Fig. 32).

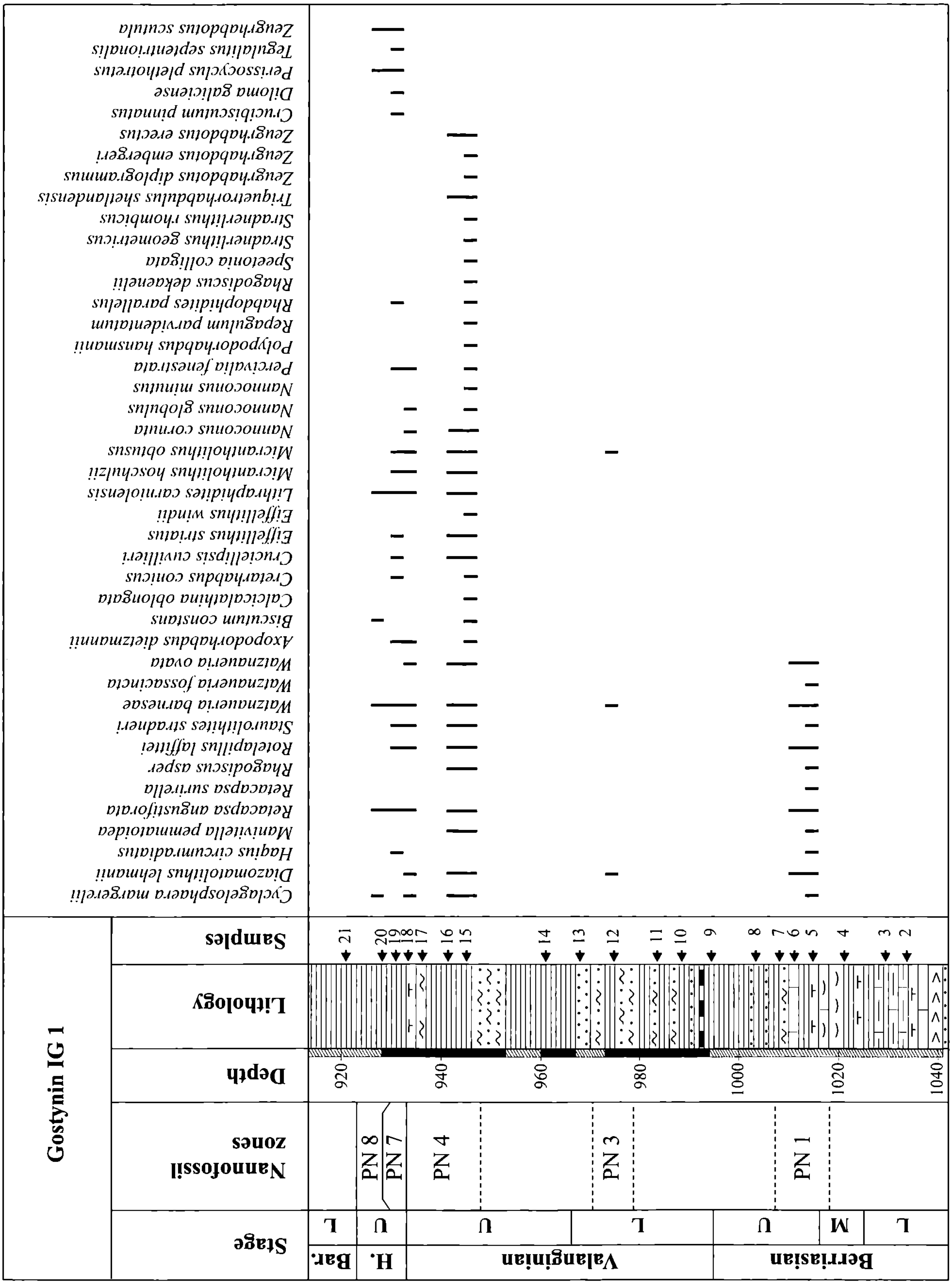


Fig. 22. Distribution chart of calcareous nannofossils in the Lower Cretaceous deposits of the Gostynin IG 1; for lithological description – see Fig. 2

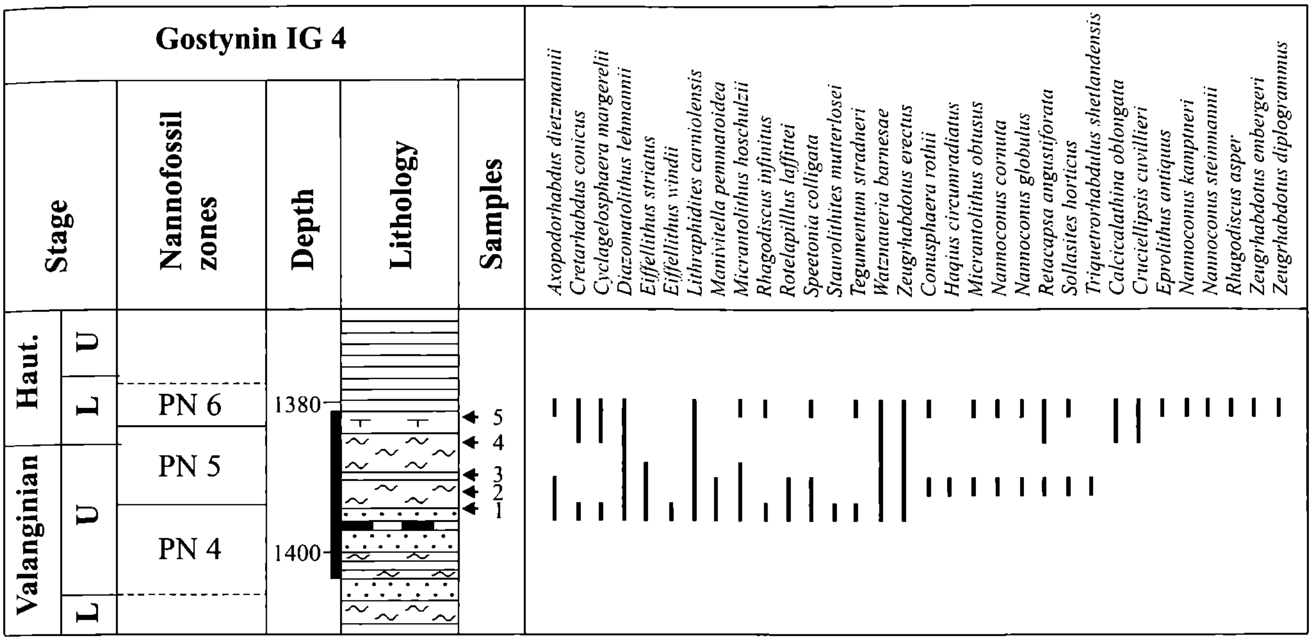


Fig. 23. Distribution chart of calcareous nannofossils in the Lower Cretaceous deposits of the Gostynin IG 4; for lithological description – see Fig. 2

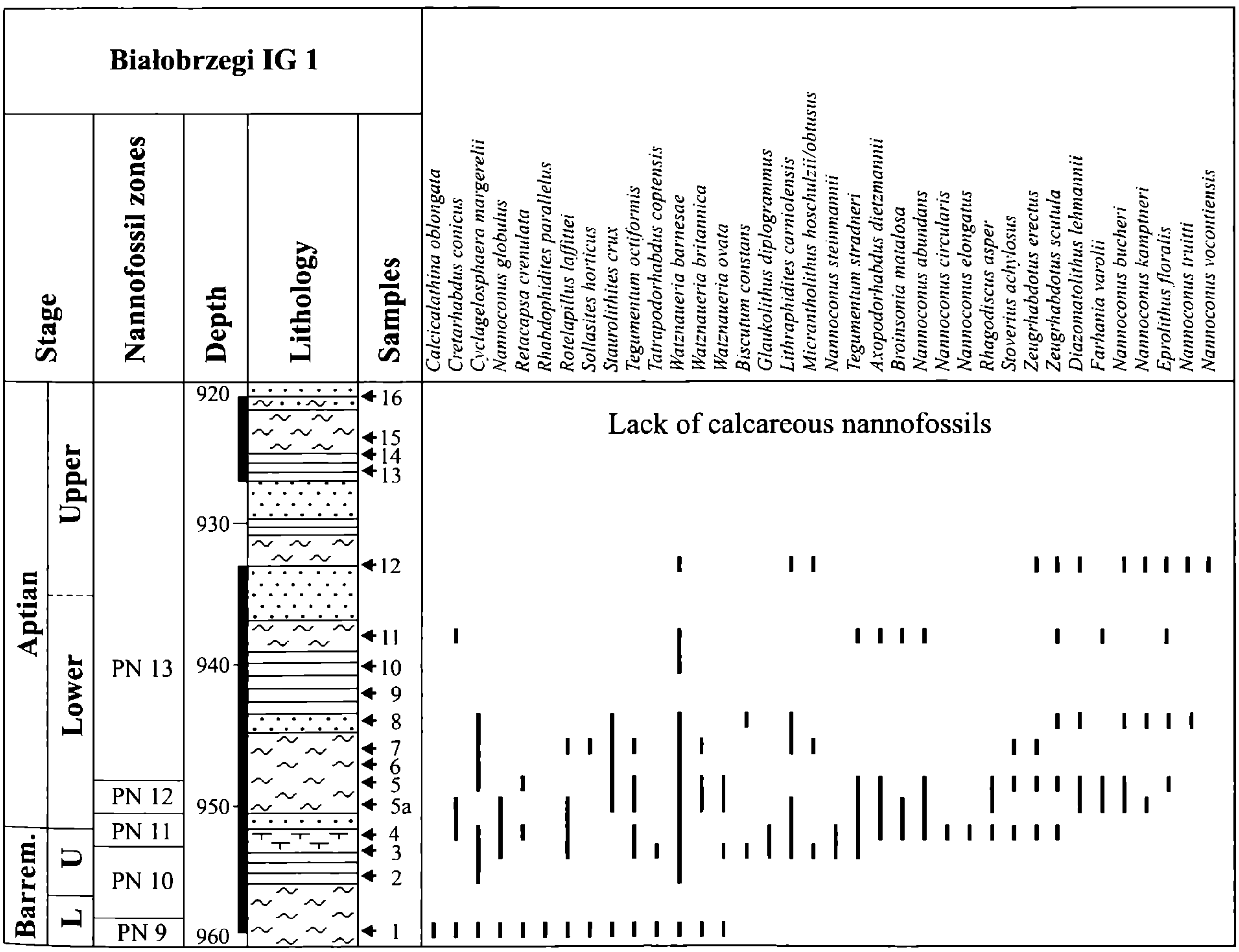


Fig. 24. Distribution chart of calcareous nannofossils in the Lower Cretaceous deposits of the Białobrzegi IG 1; for lithological description – see Fig. 2

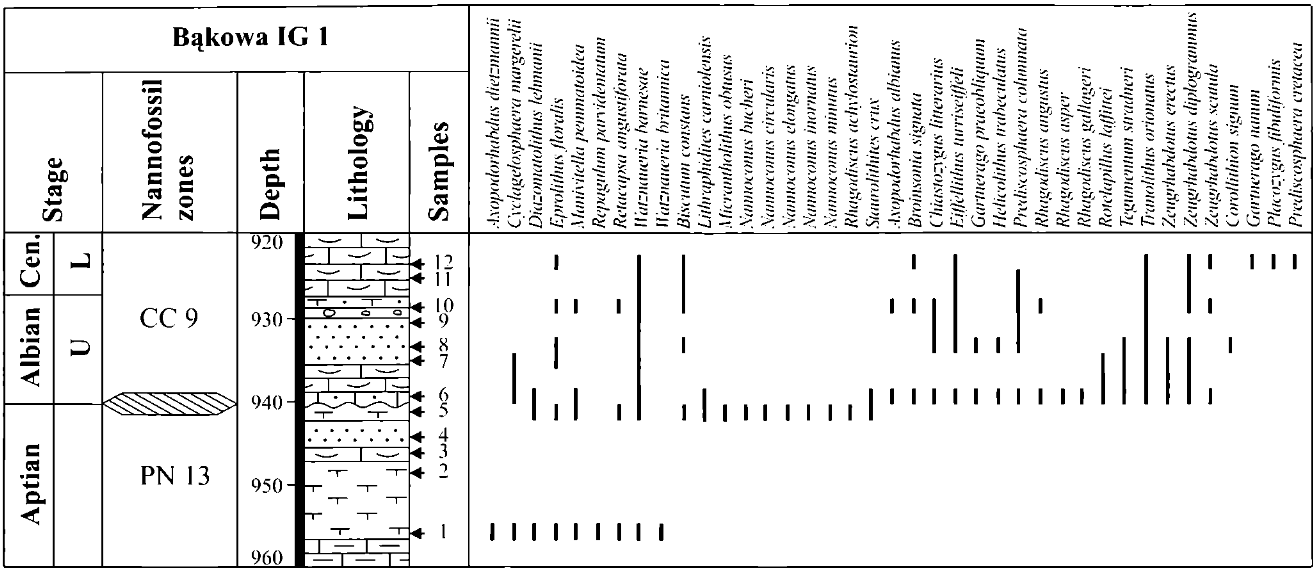


Fig. 25. Distribution chart of calcareous nannofossils in the Lower Cretaceous deposits of the Bąkowa IG 1; for lithological description – see Fig. 2

Remarks: According to Bown *et al.* (1999), *Eiffellithus striatus* appears in the Boreal Province only in the uppermost Valanginian. This, however, contradicts the observations by Mutterlose (1991), who observed the FO of this species at the boundary between the Lower and Upper Valanginian. He has also accepted this event as a cause for the distinction of biostratigraphic zone. In the studied sections of central Poland, the FO of *E. striatus* has been observed in sedimentary successions with boreal ammonites of the *hollwedensis* Zone (lower part of the Upper Valanginian), and simultaneously with numerous tethyan ammonites characteristic of the *verrucosum* Zone (Fig. 3). Also in the nannofossil assemblages, a co-occurrence of tethyan and boreal species was observed. *E. striatus* is largely frequent in studied sections (Gostynin IG 1, Gostynin IG 4, Wąwał clay-pit; Figs. 22, 23). Zone PN 4 was distinguished in the lower part of the Włocławek Formation.

PN 5 *Conusphaera rothii*

Definition: Interval between the FO of *Conusphaera rothii* and the FO of *Eprolithus antiquus*.
Author: Mutterlose (1991).
Stratigraphic range: Uppermost Valanginian–lowermost Hauterivian. The interval corresponding to the Valanginian ammonite *tuberculata* Zone and the Lower Hauterivian *amblygonium* Zone.
Remarks: In the Tethyan Realm, *C. rothii* appears probably earlier, in the uppermost Tithonian (Bown *et al.*, 1999). In Poland, however, similarly as in the German Basin and in the Boreal Realm, the FO of this species was observed only in the uppermost Valanginian (Gostynin IG 4; Fig. 23). Also other tethyan species, such as *Lithraphidites carniolensis* (Fig. 28G), *Micrantolithus obtusus* (Fig. 28H), *Nannoconus cornuta* and *Nannoconus globulus* are frequent in this zone. *Eiffellithus striatus* is still present. The lower part of the Włocławek Formation, developed in the studied area as sandy mudstones with intercalation of dark argillaceous shales, was attributed to the zone PN 5 *Conusphaera rothii*. This zone has been identified in the cored sections from Gostynin IG 4 (Fig. 23) and Zagorzyce 7 in the Carpathian Foredeep.

PN 6 *Eprolithus antiquus*

Definition: Interval between the FO of *Eprolithus antiquus* and the FO of *Perissocyclus plethotretus*.
Author: Crux (1989), emend. Gaździcka (this paper).
Stratigraphic range: The higher part of the Lower Hauterivian, corresponding to the Boreal *noricum* and *regale* ammonite zones and the lowermost part of the Upper Hauterivian, comprising the lower part of the *Aegocrioceras* sp. Zone.
Remarks: *E. antiquus* belongs to the boreal species, absent in the Tethyan Province. In England, it appears in the *amblygonium* Zone (lowermost Hauterivian). In the studied sequences, this species appears similarly as in Germany, in the upper part of the Lower Hauterivian, corresponding probably to the *noricum* Zone (Figs 21, 23). However, the definition of the zone proposed by Mutterlose (1991), who accepts the LO of this species as a stratigraphically significant event, is difficult to accept. Because of the scarce presence of *E. antiquus* in the studied sequences, different event has been proposed as a marker of the upper boundary of this zone. It corresponds to the FO of *Perissocyclus plethotretus* (Fig. 21). This zone has been distinguished in the cored sections from Łowicz IG 1 (Fig. 21) and Gostynin IG 4 (Fig. 23), in sedimentary successions of the lower part of the Włocławek Formation.

PN 7 *Perissocyclus plethotretus*

Definition: Interval between the FO of *Perissocyclus plethotretus* and the FO of *Tegulalitus septentrionalis*.

Author: Gaździcka (this paper).
Stratigraphic range: Lower part of the Upper Hauterivian, corresponding to the upper part of the *Aegocrioceras* spp. Zone and the lowermost part of the *staffi* Zone in the Boreal Realm.
Remarks: In the Polish Basin, *P. plethotretus* appears abundantly and slightly earlier than *Tegulalithus septentrionalis*. It seems that this event may be useful for identifying of the Upper Hauterivian sequences, in which the ammonites are absent. The zone PN 7 *Perissocyclus plethotretus* was recognized in the cored sections from Gostynin IG 1 (Fig. 22), Łowicz IG 1 (Fig. 21), and Żychlin IG 3.

PN 8 *Tegulalithus septentrionalis*

Definition: Interval corresponding to the total range of *Tegulalithus septentrionalis*.
Author: Crux (1989).
Stratigraphic range: Upper Hauterivian, corresponding to the higher part of the boreal *staffi* ammonite Zone and the lowermost part of the *gottschei* Zone.
Remarks: Similarly as in the German Basin, the nannoplankton assemblages include abundant *Watznaueria barnesae* and *Rhagodiscus asper*. *Cruciellipsis cuvillieri* is present only in the lower part of this zone; *Speetonia colligata* has not been found. The PN 8 *Tegulalithus septentrionalis* Zone was recognized in the cored sections from Łowicz IG 1 (Fig. 21), and Gostynin IG 1 (Fig. 22). It includes the upper part of the Włocławek Formation.

PN 9 *Tegumentum octiformis*

Definition: Interval between the LO of *Tegulalithus septentrionalis* and the FO of *Nannoconus abundans*.
Author: Mutterlose (1991).
Stratigraphic range: Uppermost Hauterivian, lowermost Barremian.
Remarks: In the Boreal Realm as well as in Germany, *T. septentrionalis* occurs for the last time in the upper part of the *gottschei* ammonite zone. PN 9 comprises the uppermost part of the *gottschei* Zone and the *discofalcatus* Zone, established in Germany, including the uppermost Hauterivian and the lowermost Barremian. The upper part of this zone was identified in cored section from Białobrzegi IG 1 (Fig. 24). Nannofossil assemblages are poorly diversified. Some tethyan taxa (e.g., *Calcicalathina oblongata* and nannoconids) were recorded in this interval.

PN 10 *Nannoconus abundans*

Definition: Interval between the FO of *Nannoconus abundans* and the FO of *Broinsonia matalosa*.
Author: Crux (1989) emend. Gaździcka (this paper).
Stratigraphic range: Lower and Upper Barremian (without the uppermost part).
Remarks: *N. abundans*, belonging to the boreal taxa, is not abundant in the studied samples. It was found in the cored sections from Białobrzegi IG 1 (Fig. 24). This is the southernmost finding of this species in Europe.

PN 11 *Broinsonia matalosa*

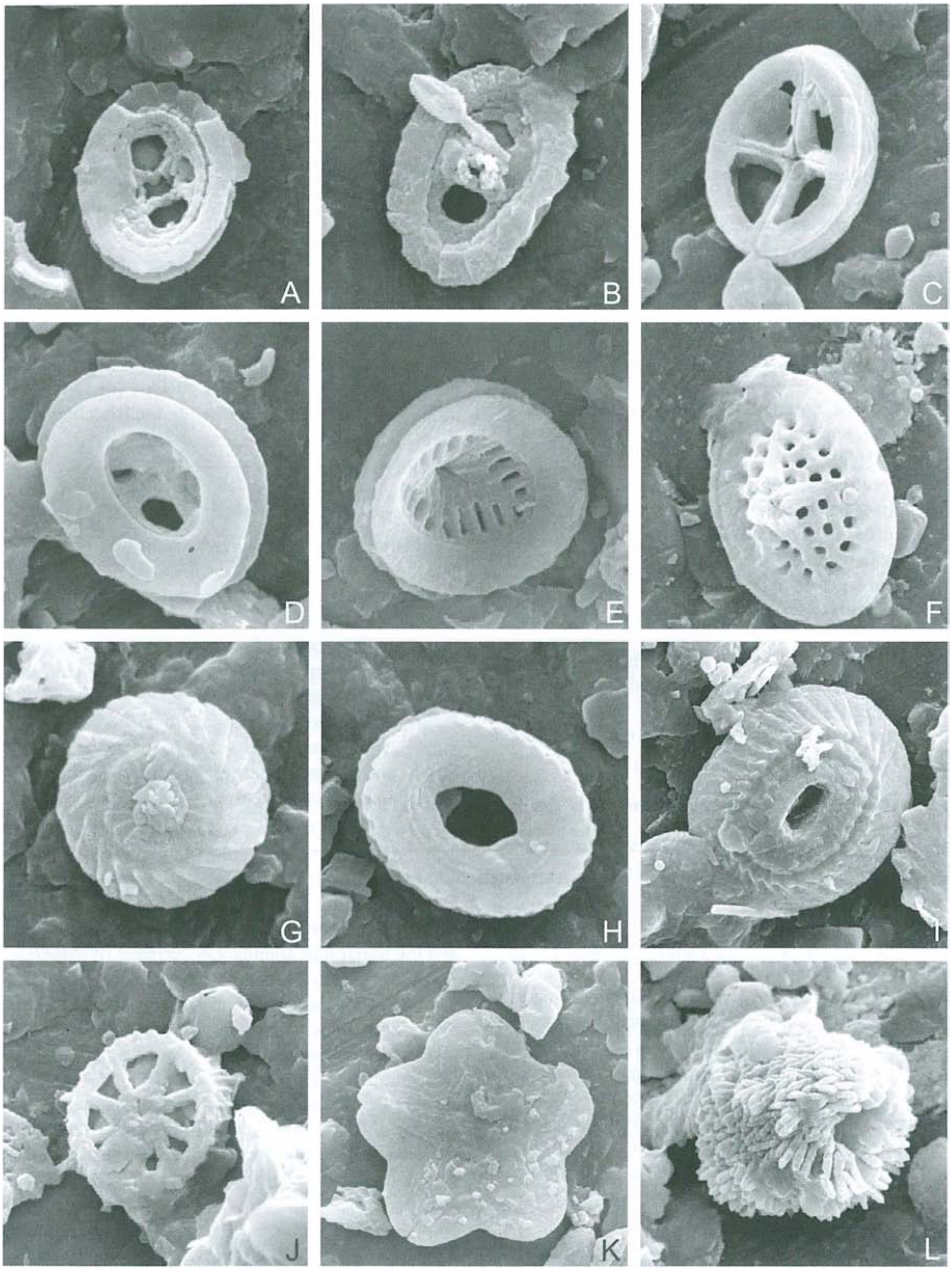
Definition: Interval between the FO of *Broinsonia matalosa* and the FO of *Farhania varolii*.
Author: Mutterlose (1991), emend. Gaździcka (this paper).
Stratigraphic range: Uppermost Barremian, lowermost Aptian, corresponding to the Boreal (German) Upper Barremian *stolleyi* and *bidentatum* ammonite zones and the Lower Aptian *tenuicostatus* Zone, as well as the lower part of *deshayesi* Zone (Fig. 32).
Remarks: In the Upper Barremian of the German Basin, Mutterlose (1991) emphasized the occurrence of scarce and poorly diversified calcareous nannoplankton assemblages. Samples taken from the cored section from Białobrzegi IG 1 provided the abundant nannofossil assemblages, with a large amount of the tethyan species (including nannoconids). PN 11 was distinguished in the Białobrzegi IG 1 section (Fig. 24).

PN 12 *Farhania varolii*

Definition: Interval between the FO of *Farhania varolii* and the FO of *Eprolithus floralis*.
Author: Rutledge and Bown, emend. Gaździcka (this paper).
Stratigraphic range: Lower Aptian, corresponding to the middle and the upper parts of the *deshayesi* ammonite zone, distinguished in the German Basin.
Remarks: *F. varolii*, belonging to the boreal species, is also known from the German Basin, where it occurs in the Lower and Upper Aptian. PN 12 was also distinguished in the section of Białobrzegi IG 1 (Fig. 24).

PN 13 *Eprolithus floralis*

Definition: Interval between the FO of *Eprolithus floralis* and the horizon of abundant occurrence of *Nannoconus*.
Author: Gaździcka (this paper).
Stratigraphic range: Upper part of the Lower Aptian, corresponding to the uppermost part of the *deshayesi* ammonite zone and the lower part of the Upper Aptian (tethyan – *furcata* and boreal *bowerbanki* zones).
Remarks: *Eprolithus floralis* (Fig. 30I) appeared in the upper part of the Lower Aptian (*deshayesi* Chron) in both the Tethyan and Boreal Realms. This event may be also observed in the cored section from Białobrzegi IG 1, at the depth of 949 m (Fig. 24). The marker species of PN 13 is accompanied by: *Broinsonia matalosa*, *Farhania varolii*, *Rhagodiscus asper*, and representatives of the genus *Nannoconus*. The frequency of nannoconids clearly increases in the highest part of the studied succession. There appear also some new species like e.g., *Nannoconus truitti* and *Nannoconus vocontiensis*. The abundant nannoconids were also found in the cored section from Bąkowa IG 1, at a depth of 942.3 m (Fig. 25). Mutterlose (1991) accepted this horizon as the upper boundary of the PN 13 Zone. In the lower Saxony Basin, the horizon of abundant occurrence of the genus *Nannoconus* is correlated with the boundary between the Lower and the Upper Aptian.



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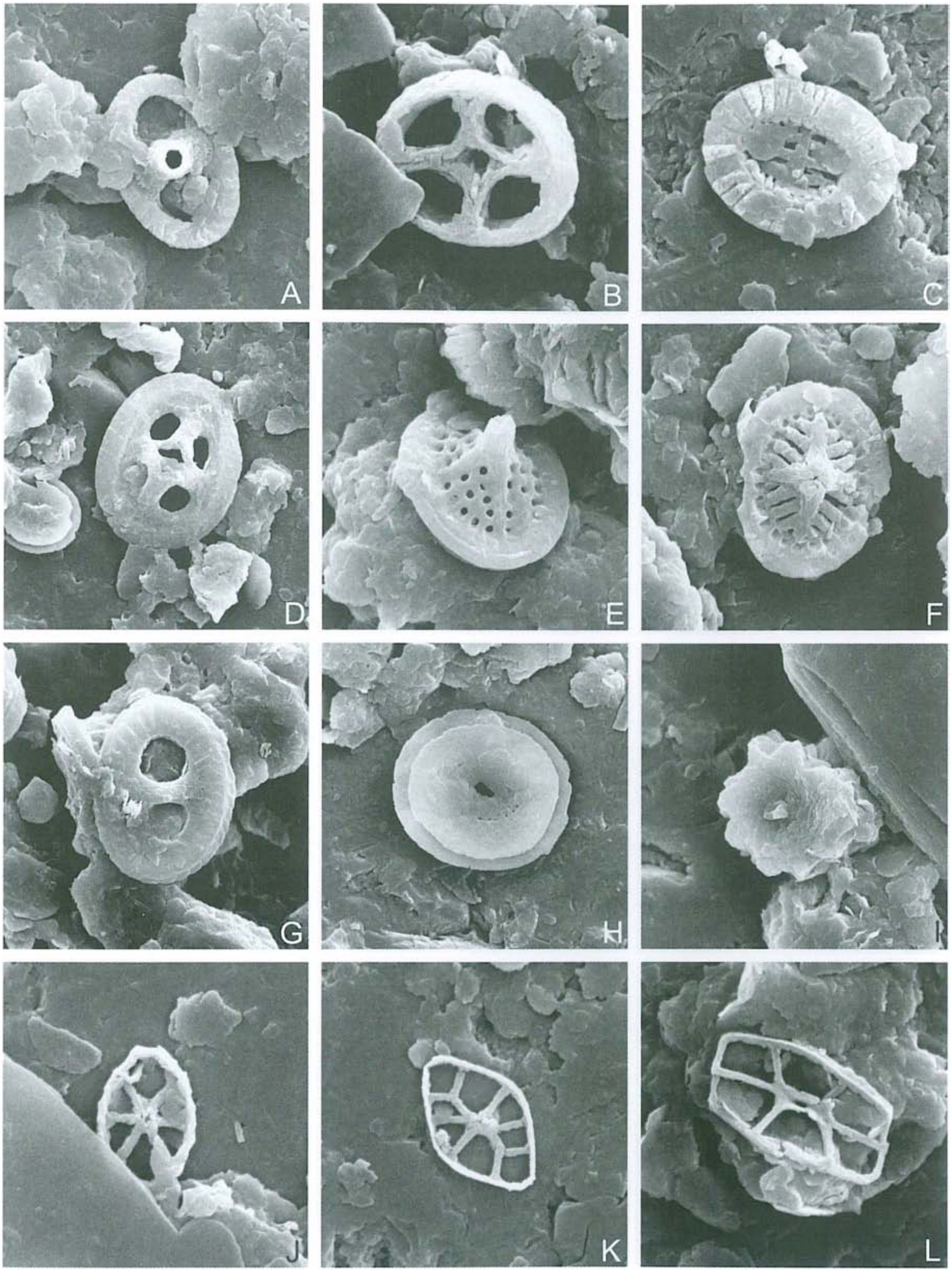

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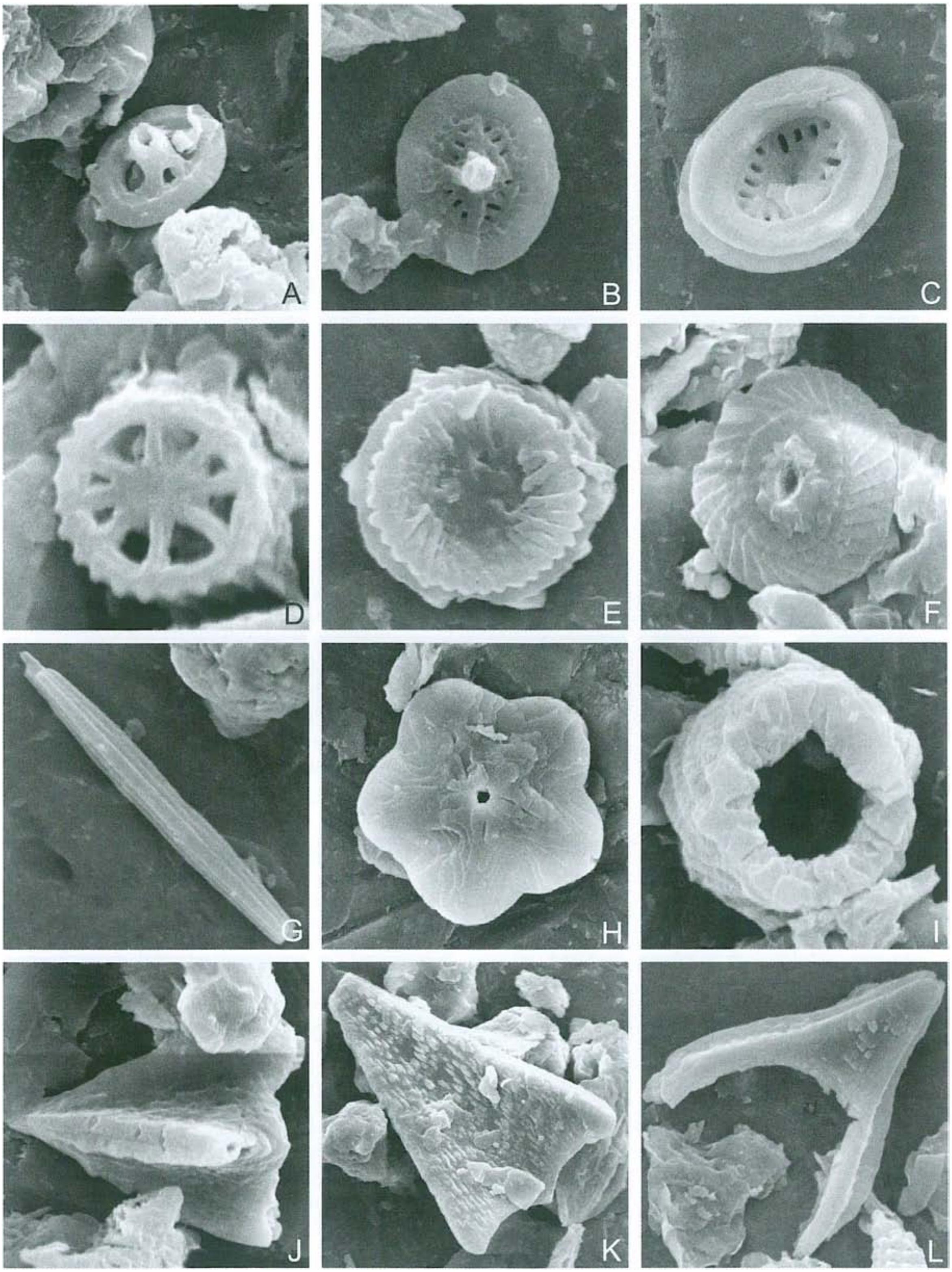
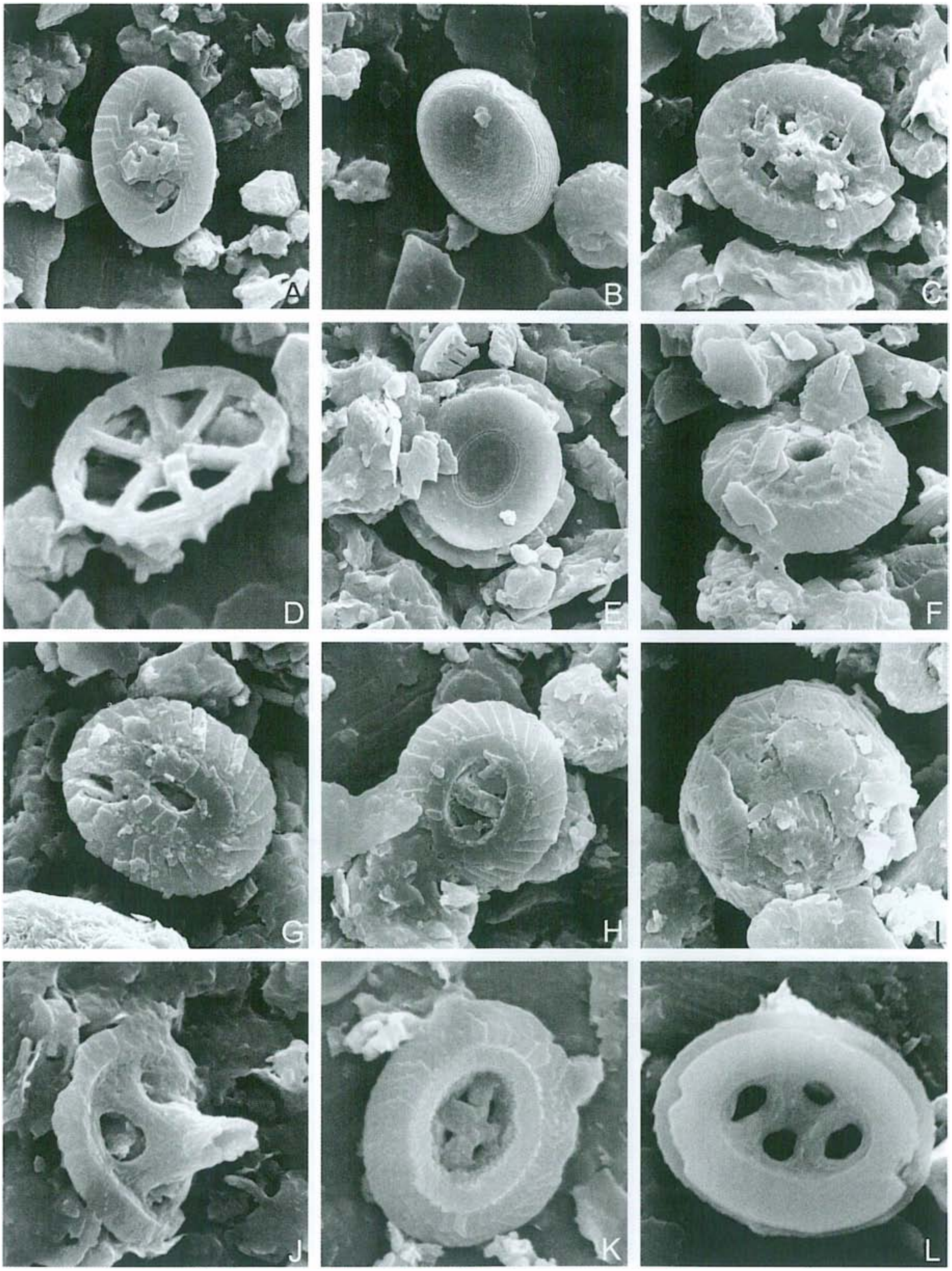


Fig. 28. **A.** *Tetrapodorhabdus coptensis* Black, distal view, ×6.000; **B.** *Retacapsa crenulata* (Bramlette et Martini), distal view, ×6.500; **C.** *Retacapsa surirella* (Deflandre et Fert), proximal view, ×7.500; **D.** *Rotelapillus laffittei* (Noël), proximal view, ×15.000; **E.** *Cyclagelosphaera margerelii* Noël, proximal view, ×7.500; **F.** *Watznaueria barnesae* (Black), distal view, ×7.500; **G.** *Lithraphidites carniolensis* Deflandre, ×6.000; **H.** *Micrantholithus obtusus* Stradner, proximal view, ×7.500; **I.** *Nannoconus circularis*, Deres et Achéritéguy, ×7.500; **J.** *Triquetrorhabdulus shetlandensis* Perch-Nielsen, ×6.000; **K.** *Triquetrorhabdulus shetlandensis* Perch-Nielsen, ×3.000; **L.** *Ceratolithoides* sp. A, ×5.000. A–L: Łowicz IG 1 (752.5 m), Lower Hauterivian, *radiatus* Zone; calcareous nannoplankton Zone: NP 6 *Eprolithus anti-*



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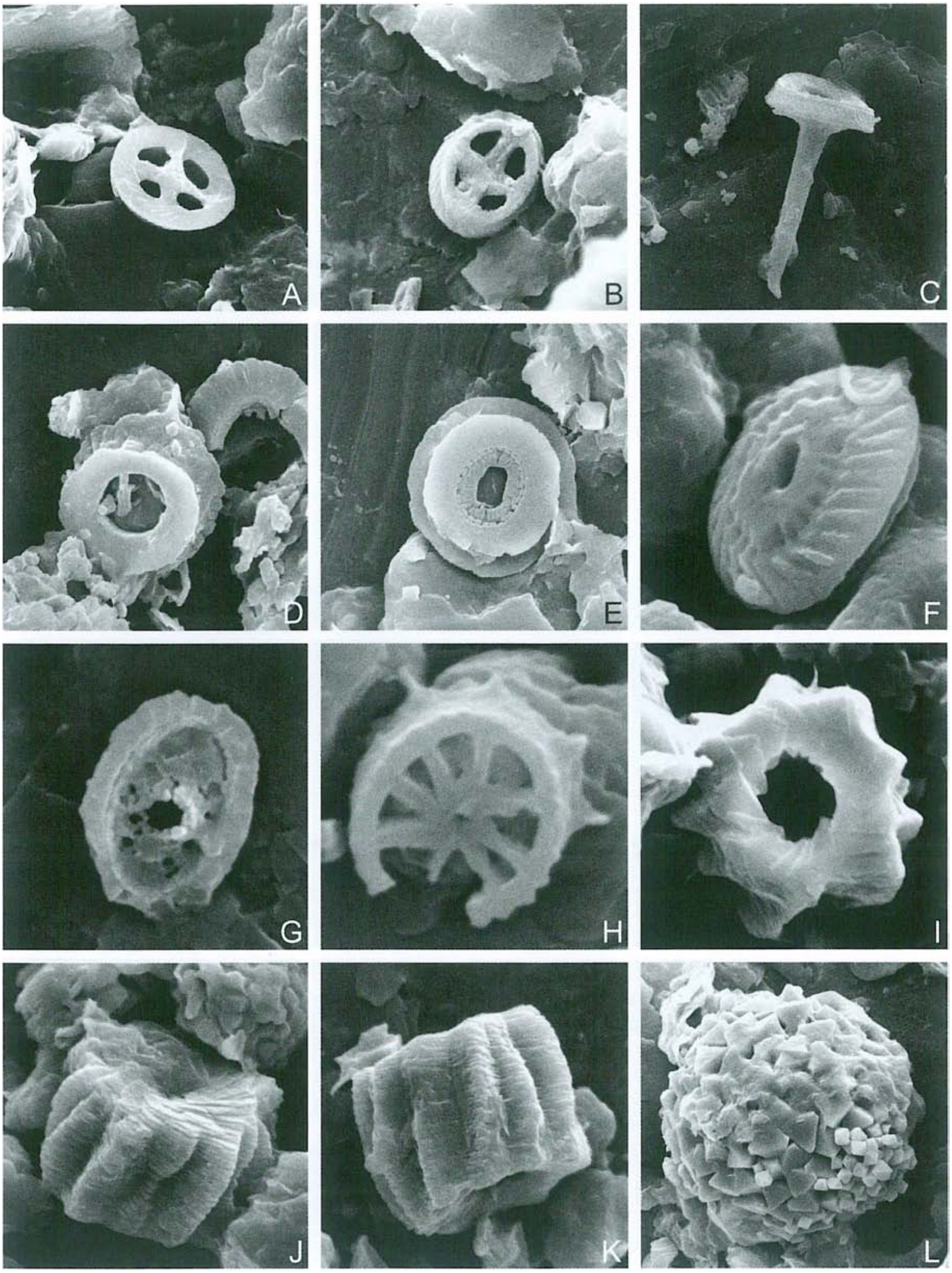

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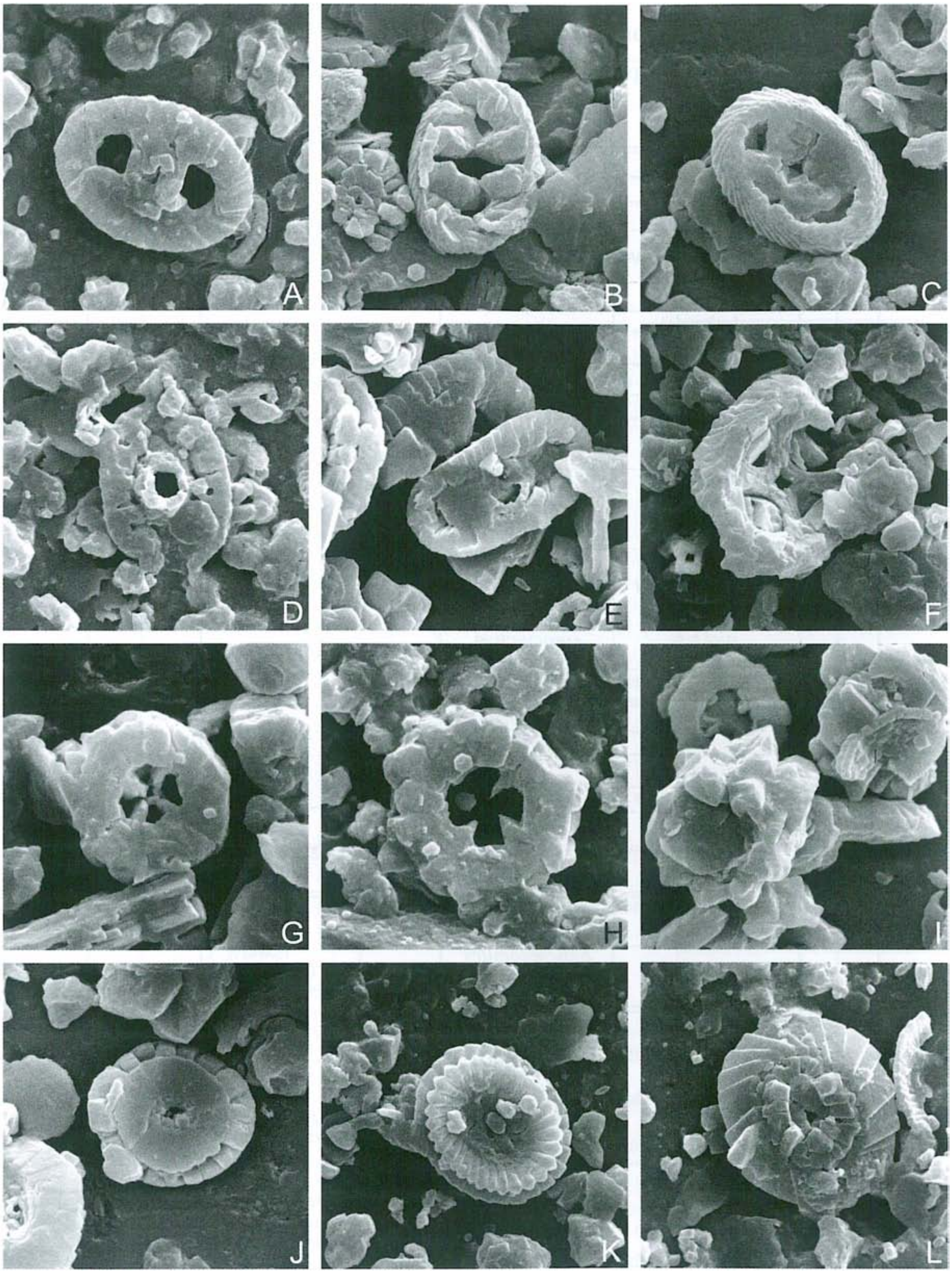

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Stage	Age (mln years)	Duration	Substage	Ammonite zones: Tethyan	Ammonite zones: Boreal (German)	"Beds" with ammonites Extra-Carpathian Poland (Marek, 1997; Marek & Shulgina 1996)	Ammonite zones Extra-Carpathian Poland *et al.*, Tethyan	Ammonite zones Extra-Carpathian Poland *et al.*, Boreal (German)
Aptian		5	U	*jacobi*	*jacobi*			
			U	*nolani*	*nolani*			
			U	*melchioris*	*nutfieldiensis*			
			U	*subnodosocostatum*	*tschernyschewi*			
			U		*drewi*			
			L	*furcata*	*bowerbanki*			Lower Aptian
			L	*deshayesi* *weissi*	*deshayesi*			
			L	*oglanlensis* *waagenoides*	*tenuicostatus*			
Barremian	113	2.5	U	*sarasini* *giraudi*	*bidentatum*			
			U	*feraudianus*	*stolleyi*			
			U	*sartousiana*	*innexum*			
			U	*vandenheckii*	*denckmanni*			
			L	*darsi* *compressissima*	*elegans*			
			L	*pulchella*	*fissicostatum*			
			L	*nicklesi*	*rarocinctum*			
			L	*hugii*	*discofalcatus*	"Beds" with *Simbirskites*		
Hauterivian	116.5	4.5	U	*ohmi*				
			U	*balearis*	*gottschei*			*gottschei*?
			U	*ligatus*	*staffi*			
			U	*sayni*	*Aegocrioceras* sp.			
			L	*nodosoplicatum*				
			L	*loryi*	*regale*	"Beds" with *Endemoceras*		
			L		*noricum*			*noricum*?
			L	*radiatus*	*amblygonium*		*radiatus*	*amblygonium*?
Valanginian	121	7	U	*furcillata*	*'asteria' fauna*	"Beds" with *Dichotomites* and *Saynoceras*		
			U		*tuberculata*			
			U	*peregrinus*	*bidichotomites*			
			U		*triptychoides*			*triptychoides*
			U	*verrucosum*	*crassus*		*verrucosum*	*crassus, polytomus*
			U		*polytomus*			
			L	*campylotoxus*	*hollwedensis*			
			L		*sphaeroidalis*	"Beds" with *Polyptychites*		
			L		*clarkei*			
			L		*multicostatus*			
			L	*petransiens*	*pavlowi*		*petransiens*	
			L		*involutum*	"Beds" with *Platylenticeras*, *Neocomites* and *Karakaschiceras*		
			L		*heteropleurum*			*heteropleurum*
			L		*robustum*			*robustum*
Berriasian	128	6	U	*boissieri*	*"weald"*	"Beds" with *Surites*, *Euthymiceras* and *Neocosmoceras*		U. Ber.
			M	*occitanica*		"Beds" with *Riasanites*, *Himalayites* and *Picteticeras*		
			L	*jacobi*				

Fig. 32. A comparison of Lower Cretaceous ammonite, foraminifer, ostracod and nannofossil zonations; stratigraphic scheme proposed for the studied sequences. Ammonite zonation after Kemper *et al.* (1981), Bown *et al.* (1999), Kutek *et al.* (1989) and Hoedemaeker *et al.*

Ostracod zones (used in this paper by Smoleń) (Bielecka & Sztejn 1966)	(Anderson, 1985)	(Kubiatowicz, 1983)	Characteristic foraminiferal assemblages (Smoleń, this paper)	Nannoplankton zones (Mutterlose, 1991; emend. Gaździcka, this paper)
				PN 13 *Eprolithus floralis*
			Assemblage with *Gavelinella barremiana* *Hedbergella infracretacea*	PN 12 *Farhania varolii*
				PN 11 *Broinsonia matalosa*
				PN 10 *Nannoconus abundans*
			Assemblage with *Lagena hauteriviana cylindrica, Citharina sparsicostata* *Citharina orthonota*	PN 9 *Tegumentum octiformis*
				PN 8 *Tegulalithus septentrionalis*
				PN 7 *Perissocyclus plethotretus*
				PN 6 *Eprolithus antiquus*
		P. frankei	Assemblage with *Hechtina praeantiqua* *Protomarssonella hechti* *Protomarssonella kummi*	PN 5 *Conusphaera rothii*
			L. eichenbergi Zone (after Moullade, 1984)	PN 4 *Eiffellithus striatus*
		P. aubersonensis	Assemblage with *Epistomina caracolla* *Lenticulina subalata* Assemblage with *Glomospirella gaultina* *Ammodiscus tenuissimus* Assemblage with *Epistomina caracolla* *Lenticulina subalata* *Verneuilinoides neocomiensis*	PN 3 *Watznaueria barnesae*
				PN 2 *Zeugrhabdotus diplogrammus*
		P. propria emslandensis	Assemblage with *Trochammina inflata* *Haplophragmoides concavus* *Ammobaculites agglutinans*	PN 1 *Retacapsa angustiforata*
A	*C. vidrana*			
B	*C. granulosa*		Assemblage with *Verneuilinoides faraonica* *Verneuilina subminuta* *Verneuilinoides angularis.*	
C D E	*C. dunkeri*			

(2003); ammonite zones established in this paper – in grey

In the Białobrzegi IG 1 section, the arenaceous series overlying the silty succession, with nannofossils of the zone NP13 *Eprolithus floralis*, is correlated with the Mogilno Formation distinguished in the Polish Lowlands (Marek, 1997). These sandy successions usually do not contain any marine fossils that would permit determination of their stratigraphic position. This series is present in most studied sections within the Warsaw Trough (Fig. 43). Calcareous nannoplankton assemblages appear only in glauconitic sands and sandstone from Gostynin IG 1 (at depth 738 m) or in marls underlying these glauconitic sands (Bąkowa IG 1, depth 941 m). Their taxonomic composition allows distinguishing the standard, upper Albian nannoplankton zone CC 9 *Eiffellithus turriseiffeli* (Perch-Nielsen, 1985) or the boreal one – BC 27 (Bown *et al.*, 1999). The CC 9 Zone comprises the uppermost Albian and the Lower and Middle Cenomanian. Its lower boundary corresponds to the upper part of the ammonite *inflatum* Zone (Bown *et al.*, 1999). The British BC 27 Zone comprises a shorter stratigraphic interval than the standard CC 9 Zone, corresponding only to the uppermost Albian and the lower part of the Lower Cenomanian *mantelli* Zone. Deposits corresponding to the BC 27 (or CC 9) Zone have been distinguished in the sections of Gostynin IG 1 and Bąkowa IG 1 (Fig. 25), as well as in glauconitic sands from the abandoned gravel pit in Annopol. Besides *Eiffellithus turriseiffeli* (Fig. 31F) – the index species for the mentioned zones – the nannoplankton assemblages include also other species that appear for the first time in the Upper Albian, such as: *Axopodorhabdus albianus*, *Gartnerago praeobliquum*, *Prediscosphaera columnata* (Fig. 31G, H), and *Tranolithus orionatus* (Fig. 31B, C). No Lower Cenomanian nannofossil species were found in the studied sections.

Stratigraphic position of the sedimentary succession from the Wąwał clay-pit has been attributed to the Lower and partly Upper Valanginian, on the basis of ammonite assemblages. It was correlated with the *petransiens*, *campylotoxus*, *verrucosum*, and *trinodosum* zones (Fig. 3). The lowermost layers in the section, representing the Lower Valanginian, contain almost monospecific coccolith assemblages with *Watznaueria barnesae* (Black). They may be thus included into the nannoplankton zone NP 3 *Watznaueria barnesae* and correlated with the lowermost strata of the Bodzanów Formation from Gostynin IG 1 and Łowicz IG 1 sections (Figs 21, 22). The taxonomic impoverishment of the nannoplankton assemblages was also observed in the Lower Valanginian sediments of the Lower Saxony Basin (Mutterlose, 1991). The sedimentary successions with the ammonites of the *verrucosum* Zone have been there attributed to the *Tegumentum striatum* Zone (Mutterlose, 1991). This zone includes the Upper Valanginian, without the uppermost part corresponding to the ammonite *tuberculata* Zone. This interval is correlated with the "Beds with *Dichotomites*", that were established in the German Basin (Mutterlose, 1991).

The stratigraphic position of the Białobrzegi Formation recognised in the southern part of the Warsaw Trough and in the north-eastern margin of the Holy Cross Mountains has also been revised. In the cored section from Białobrzegi IG 1, nannofossil zones: PN 9 through PN 13, corresponding to the Upper Barremian and Lower Aptian, have been found in a clayey-marly sequences with intercalation of carbonates and glauconite-bearing sandstone (Figs 24, 25). The Białobrzegi Formation has hitherto been included in the Upper Valanginian and Lower Hauterivian (Marek, 1977b, 1997). The Cieszanów Formation from boreholes Narol IG 1 and Narol IG 2 may be included in the nannoplankton zone PN 9, comprising the Upper Hauterivian and Lower Barremian, and not the Upper Valanginian and Lower Hauterivian, as it was accepted previously (Marek, 1997). The appearance of *Eprolithus floralis* (Fig. 24) and of the horizon of abundant *Nannoconus* (Fig. 25) are the last "events" observed in the studied Lower Cretaceous sedimentary series beneath the Mogilno Formation, barren in fossils. The age of the host sediments, by analogy with the German Basin, was determined as the Lower Aptian. Another episode of flourishing nannofloral assemblages occurred only in the Late Albian. Nannoplankton assemblages rich in specimens and taxonomically diversified have been recorded in glauconitic sands from the cored sections from Gostynin IG 1 (depth 738–740 m) and Bąkowa IG 1 (depth 925–941 m), as well as in glauconitic and marly sands from gravel-pit at Annopol. They provided base for identification of the standard nannoplankton zone CC 9 *Eiffellithus turriseiffeli*, comprising the uppermost Albian (*dispar* ammonite zone). Analysis of calcareous nannoplankton assemblages within the scope of this study allowed to attribute the sandstone of the Mogilno Formation to the stratigraphic interval comprising the Upper Aptian and Lower and Middle Albian, and not the Barremian–Middle Albian, as it was accepted before (Marek, 1997; Leszczyński, 1997).

CALCAREOUS NANNOPLANKTON VERSUS PALAEOGEOGRAPHY AND PALAEOCLIMATE

The studied Lower Cretaceous sedimentary series in central and southeastern Poland include calcareous nannoplankton assemblages with significant amount of species characteristic of the Tethyan Realm. These include genera: *Nannoconus* (Figs 26L, 28I, 30J, K), *Micrantholithus* (Figs 26K, 28H), *Lithraphidites* (Fig. 28G), *Rhagodiscus* (Fig. 31D), and *Watznaueria* (Fig. 27H) (Thierstein, 1973; Wagreich, 1992), as well as *Cruciellipsis cuvilieri* (Manivit), *Speetonia colligata* Black (Fig. 27G), and *Calcicalathina oblongata* (Worsley) (Bown *et al.*, 1999). They are accompanied by forms with less restrictive ecological requirements and by species typical of the Boreal Realm: *Eiffellithus striatus* (Black), *Tegulalithus septentrionalis* (Stradner), and *Zeugrhabdotus sisyphus* (Gartner) (Bown *et al.*, 1999). The boreal elements are, however, less numerous than the tethyan ones. The thermophilic species are especially numerous in the Upper Berriasian, lowermost Valanginian (*petransiens* ammonite Zone), the lower part of the Upper Valanginian (*verrucosum* Zone), and also in the Upper Hauterivian and Lower Aptian. The nannofloral assemblages from the higher part of the Lower Valanginian indicate cooler episodes. The occurrence of tethyan species in sediments of almost all Lower Cretaceous stages, from the Berriasian through the Aptian, indicates an opening of the Polish Basin towards the Tethys at that time. The finding of calcareous nannoplankton assemblages typical of the Early Aptian and rich in tethyan elements, suggests a possible new look at palaeogeography of the later part of the Early Cretaceous. According to the earlier interpretation, the Polish Basin was closed on the south and open only towards the north-west during the Barremian, Aptian, and Early Albian (Marek, 1988; Leszczyński, 1997). Our results, concerning the assemblages of calcareous nannoplankton, microfauna, and ammonites, contradict such an interpretation.

The calcareous nannoplankton assemblages allow also for drawing some conclusions regarding palaeocurrents. These probably had to move water masses from the south towards the north during a prevailing part of the Early Cretaceous. The palaeocurrent system in the Late Valanginian could be different, that is from the north-west towards the Polish Basin. This conclusion is based on the analysis of ammonite and calcareous nannoplankton assemblages. The ammonite assemblages in the *verrucosum* Zone include many Mediterranean forms, while the calcareous nannoplankton includes numeral boreal species. Mutterlose (1993) has even observed the occurrence of single specimens of the boreal species *Micrantholithus speetonensis* in these strata, in the Wąwał section. The amounts of tethyan coccoliths clearly increase beginning with the Lower Hauterivian, though boreal species, such as *Eprolithus antiquus*, *Tegulalithus septentrionalis*, and *Nannoconus abundans* are present in nannoplankton assemblages from central Poland.

The taxonomic composition of the nannoplankton assemblages also allows for drawing conclusions regarding basin palaeobathymetry and the distance of a studied section from the ancient shoreline. The presence of numerous calcareous dinocysts of genus *Pithonella* in the Berriasian sediments in both central and southeastern Poland indicates a very shallow sedimentary environment (shallow shelf – carbonate platform). The predominance of the representatives of genus *Micrantholithus* in the Upper Hauterivian of the southern Lublin area, accompanied by very low taxonomic diversity of the assemblages (wells: Narol IG 1, Narol IG 2), may indicate proximity of a shore and a stronger influence of the Tethyan Realm in this part of sedimentary basin.

DEPOSITIONAL SEQUENCES IN THE LOWER CRETACEOUS DEPOSITS IN CENTRAL AND SOUTHEASTERN POLAND

The large distances between the boreholes, the lack of full well-cores, and facies variability hamper a detailed subdivision and interpretation of the Lower Cretaceous strata in the studied area. That is why the method of sequence stratigraphy was used for their correlation. It allowed discerning of several types of chronostratigraphically significant features, such as transgressive surfaces, maximum flooding surfaces or sequence boundaries. These boundaries allowed for quite precise identification of several genetically related depositional systems tracts, which originated between episodes of significant sea level fall (Posamentier *et al.*, 1988), thus defining the sequences bounded at the top and at the base by unconformities or their correlative conformities (Mitchum, 1977).

An important aspect of the presented analysis is the possibility of identifying genetical sequences (*sensu* Galloway, 1989), that reflect the stratigraphic record of basin filling between two successive sea-level highstands. The division into genetic units is easier to draw only basing on wire-line logs and a small amount of cores, because the maximum flooding surfaces are easier to identify than the sequence boundaries in the EXXON scheme. These surfaces are easy to identify on geophysical logs because they occur most frequently between upward fining (retrogradational) and upward coarsening (progradational) cycles. Additionally, maximum values on gamma-ray logs are present at the same positions as the maximum flooding surfaces, which is due to the presence of highly radioactive components (Loutit *et al.* 1988; Van Wagoner *et al.*, 1990; Walker & James 1992; Emery & Myers, 1996; Miall, 1997).

Position of interpreted boundaries in all analysed wells is shown in their synthetic geological cross-sections (Figs 33–42), which additionally include:

– gamma-ray combined with neutron, as well as spontaneous potential and a selected resistivity logs,
– lithological data from cores and interpreted from well log data in the non-cored intervals,
– available palaeontological and lithofacies data,
– interpretation of sedimentary environments,
– proposal of depositional sequences,
– curve of sea-level changes.

The data thus prepared were used to plot two correlation cross-sections. The first one (Fig. 43) spans the following wells: Gostynin IG 4, Gostynin IG 1, Gostynin IG 3, Żychlin IG 1, Łowicz IG 1, Korabiewice PIG 1, Warka IG 1, Białobrzegi IG 1, Potok IG 1 (Warsaw Trough), Narol IG 1, and Narol IG 2 (SE part of Lublin Trough). The other (Fig. 44) starts from the Narol IG 1 (which connects the two cross-sections), and then runs through wells situated at the front of the main Carpathian overthrust near Rzeszów, that is: Nawsie 1, Zagorzyce 6, Zagorzyce 7, Ropczyce 7, Stasiówka 1, Dębica 2, Wola Wielka 2, and Wiewiórka 4. This cross-section could be drawn, despite of the 250-km distance between wells Narol IG 1 and Nawsie 1, because the Lower Cretaceous deposits in these areas are closely related in facies. The complex, blocky geological structure along the lines of both sections, and the fact that the Lower Cretaceous deposits occur at different depths did not allow for presentation of all data at once at readable scale. For this reason the sections are drawn levelled to selected stratigraphic datum – the Gostynin – Narol section to the Tithonian–Berriasian boundary, and the Narol – Wiewiórka section to the Berriasian–Valanginian boundary (Figs 43, 44). They are accompanied by the sections drawn through the same wells, but showing true depths of the studied deposits (Figs 45, 46). All cross-sections were made preserving the horizontal and vertical scales. A detailed list of the depths of occurrence of successive stratigraphic stages in the studied well sections is shown in Tables 1 and 2.

Table 1

Depth of the Lower Cretaceous stratigraphic boundaries in the wells of SW part of the Warsaw Trough and SE part of the Lublin Trough

Well:	Gostynin IG-4	Gostynin IG-1	Gostynin IG-3	Zychlin IG-3	Łowicz IG-1	Korabie-wice PIG-1	Warka IG-1	Bialobrzegi IG-1	Potok IG-1	Narol-IG-2	Narol IG-1
X-Distance: [m]	0.0	6500.0	24900.0	50500.0	76500.0	108500.0	160500.0	177500.0	318600.0	390200.0	399200.0
Cenomanian/ Turonian	1159.3	736.6	Lack	599.3	292.1	1478.8	1109.4	832.6	225.0	1341.0	1371.0
Aptian-Albian/ Cenomanian (TS)	1161.0	737.9	Lack	602.5	293.6	1496.2	1128.0	867.2	226.7	1343.0	1373.0
Barremian/ Aptian-Albian (SB)	1335.9	914.2	145.5	795.9	476.0	1617.0	1179.3	952.5	Lack	Lack	Lack
Hauterivian/Barremian (MFS)	1353.2	923.2	157.3	815.0	486.0	1623.0	1185.1	967.0	Lack	1364.4	1390.4
Lower/Upper Hauterivian (MFS	1375.0	Lack	180.0	841.0	515.0	Lack	1202.0	995.0	Lack	1369.2	1397.4
Valanginian/ Hauterivian (TS)	1387.0	930.0	203.0	860.0	531.0	Lack	1206.0	1015.0	Lack	1377.6	1410.1
Lower/Upper Valanginian (FS)	1405.0	966.0	229.9	886.0	545.0	Lack	Lack	1016.0	255.0	1392.1	1422.0
Berriasian/ Valanginian (MFS)	1427.3	996.0	265.4	915.0	572.6	Lack	1208.0	1020.0	260.0	1400.0	1435.0
Middle Berriasian (SB)	1445.0	1015.0	281.0	937.5	590.0	Lack	1216.0	1032.0	265.0	1419.5	1450.2
Lower Berriasian (FS)	1451.0	1025.0	296.0	950.0	603.0	1642.0	1229.3	1042.0	275.0	1428.3	1460.1
Tithonian/ Berriasian (SB)	1491.0	1062.0	335.0	986.0	640.0	1662.0	1261.0	1077.0	304.0	1504.1	1539.4

Lower Berriasian

The stratigraphic boundary between the Tithonian and Berriasian in Polish Lowlands was accepted at the base of a nearly 30-m-thick series of carbonate-sulphate deposits. This boundary has a regional extent and can be traced over a distance of more than 170 km. It shows distinct characteristics of a sequence boundary connected to a relative sea-level fall. Two sets of criteria, namely stratigraphical and lithological ones, allowed identifying this surface quite precisely in wire-line logs. The underlying Upper Tithonian series, developed as carbonate-marly facies, passing in the uppermost part to carbonate-evaporitic deposits, according to sedimentological data was laid down in similar environmental conditions as the Lower Berriasian succession (Gaździcka, 1996). The Lower Berriasian facies assemblage consists of alternating carbonate-sulphate deposits, including: marls, limestone, marly limestone, oolithic limestone, dolomites, gypsum and anhydrites. It was identified in cored sections from the following wells: Gostynin IG 4, Gostynin IG 1, Gostynin IG 3, Żychlin IG 3, and Łowicz IG 1. The clearly shallow-water nature of these sediments is proven by sedimentary structures, identified in anhydrites, typical of supratidal environments. Anhydrites are mostly accompanied by boundstones with laminated structures (fragments of cyanobacterial-algal mats), bird's eye structures, and numerous bioclasts. They contain exclusively remains of shallow-water benthic organisms – invertebrates, and protists. Limestone beds are locally considerably dolomitic (Gaździcka, 1996). The appearance of shallow-water evaporites is known from intracratonic basins, usually as an effect of isolation from the world ocean caused by a sea-level fall. Such conditions provide for sedimentation of a lowstand system tracts with evaporites in central parts of basins (Tucker & Chalcraft, 1991; Tucker, 1991; Walker & James, 1992, Kutek, 1994). This system tract displays a high lithological variability discernible in both the core material and geophysical well logs. The geophysical data show a clearly bipartite structure of the described series. Sulphate sediments appear twice in the section, separated by a clayey-marly series suggesting that the lowstand system tract may consist of two lower-order cycles or sequences, as has been observed also in other sedimentary basins of that type (Hondford & Loucks, 1993). This is especially well visible between wells Gostynin IG 4 and Łowicz IG 1 (Figs 33–36, 45).

Towards the southeast, this facies assemblage is replaced by a marly-carbonate facies assemblage; oolithic limestone has been found in the Białobrzegi IG 1 well. This facies variability may suggest variable sedimentary basin bathymetry along the line of the interpreted cross-section

Table 2

Depth of the Lower Cretaceous stratigraphic boundaries in the wells in the basement of the Carpathian Foredeep

Well:	Wiewiórka 4	Wola Wielka 2	Dębica 2	Stasiówka 1	Ropczyce 7	Zagorzyce 7	Zagorzyce 6	Nawsie 1
X-Distance:[m]	0	4000	14000.5	19000.5	30000.7	37000.7	38000.7	41000.0
Cenomanian/ Turonian	1422.5	1569.1	1805.2	2325.4	Lack	2703.3	2748.4	3066.1
Barremian (Aptian-Albian)/ Cenomanian	1424.9	1571.8	1806.6	2328.5	2166.0	2704.5	2750.7	3067.6
Hauterivian/ Barremian (Aptian-Albian) (MFS)	1434.8	1597.5	1829.9	2347.6	2193.7	2719.3	2772.3	3092.0
Lower/Upper Hauterivian (MFS)	1436.5	1597.5	1829.9	2347.6	2193.7	2719.3	2772.3	3092.0
Valanginian/ Hauterivian (TS)	1436.5	1603.7	1835.6	2354.1	2203.4	2726.1	2781.1	3099.5
Lower/Upper Valanginian (FS)	1436.7	1624.7	1856.2	2375.3	2233.5	2746.4	2801.1	3116.4
Berriasian/ Valanginian (MFS)	1452.6	1650.3	1882.2	2396.3	2248.7	2756.1	2813.0	3130.8
Middle Berriasian (SB)			1909.2	2412.5	2270.7	2774.1	2835.1	3150.1
Lower Berriasian (FS)			1931.7	2433.0	2288.5	2788.8	2845.2	3164.8
Tithonian/ Berriasian (SB)			1955.8	2460.6	2316.6	2815.0	2869.5	3190.8
Tithonian/ Berriasian (MFS)			1956.7	2461.5	2317.0	2815.9	2870.6	3191.3

and be the result of random selection of wells for the analysis. Marly sediments overlie the carbonate-sulphate series. In the Gostynin IG 1 well, at the base of marly sediments were found detritical-mudstone marl, very slightly dolomitic, grey, intercalated with marly limestone with few black clay-balls. The change of facies and the appearance of clay-balls at its base suggest the beginning of a transgression. The horizon with clay-balls lies on the transgression surface (TS) (Fig. 34), which marks the beginning of a transgressive systems tract. The marly facies of the transgressive system tract was found in the Gostynin IG 4 to Łowicz IG 1 wells (Figs 20–24), as well as in the Warka IG 1 and Białobrzegi IG 1 wells (Figs 33–38). A large stratigraphic gap is probably present in the Korabiewice IG 1 well. The Lower Berriasian lowstand systems tract (only one series of carbonate-sulphate deposits is present here) is directly overlain by the Upper Hauterivian deposits.

A transgressive system tract was recorded in the upper part of the Lower Berriasian. It consists of black, argillaceous and marly shales, rich in remains of small-shelled fauna, with thin intercalations of finely laminated limestone. Above this system tract, a change in the record of physical characteristics of rocks is clearly discernible in geophysical well logs, implying a facies change. A thin interval of shales, black marly shales, combined with gamma-ray log showing high values, suggests that this may be a condensed interval. A boundary of marine flooding surface may lie within it (Fig. 37), which is also the boundary between the Lower and Middle Berriasian. In the area of wells Narol IG 1 and Narol IG 2, the Lower Berriasian deposits were also laid down in a zone of a shallow-water carbonate platform. However, the thickness of these strata is there almost twice greater (about 80 m), which may be related to deposition in a zone that was tectonically less active, hence less subject to erosion of older deposits, but with a permanent trend of sedimentary basin bottom subsidence. Three lower-order depositional sequences may be distinguished in these wells. The uppermost sequence continues to the very boundary between the Middle and Upper Berriasian (Figs 39, 42).

Similar sequences are difficult to distinguish in the peri-Carpathian part, because of the nearly fourfold thickness reduction. The bottom of the Berriasian deposits is also marked by a sequence boundary in the basement of the Carpathian Foredeep (Figs 40, 41). It is possible that the age boundary lies somewhat lower, within a distinct argillaceous horizon, interpreted as a flooding surface (FS). This boundary is nearly coincident with that proposed by Zdanowski *et al.* (2001). It separates the Tithonian strata laid down in lagoon and tidal flat (Ropczyce Series – calcareous-dolomitic member) and the Lower Berriasian deposits (Ropczyce Series – calcareous-marly member), that formed in a similar environment, but with the presence of near-shore lake sediments (Zdanowski *et al.*, 2001). These were thus extremely shallow-water environments, similar to those prevailing in the northern part of the study area. The

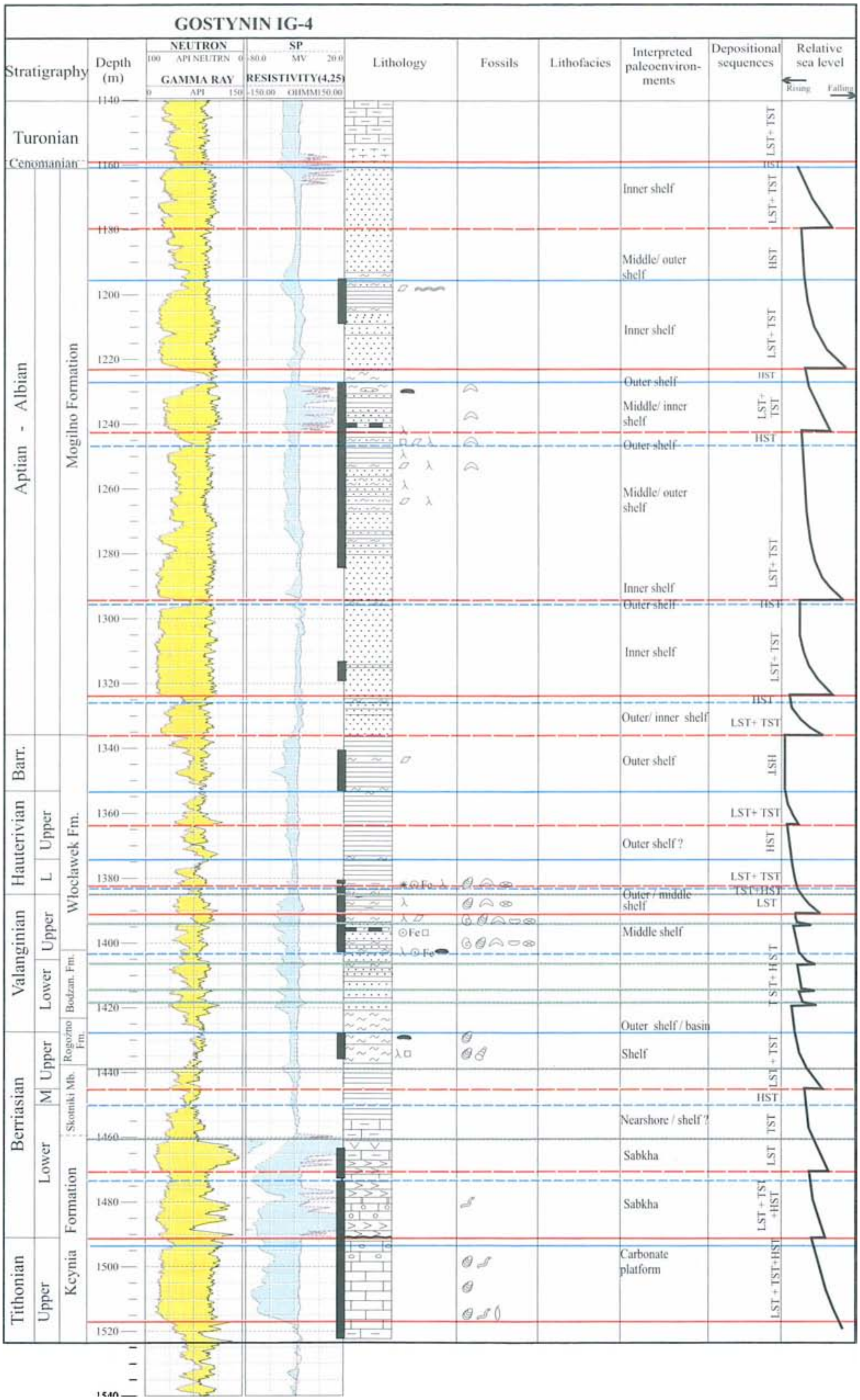
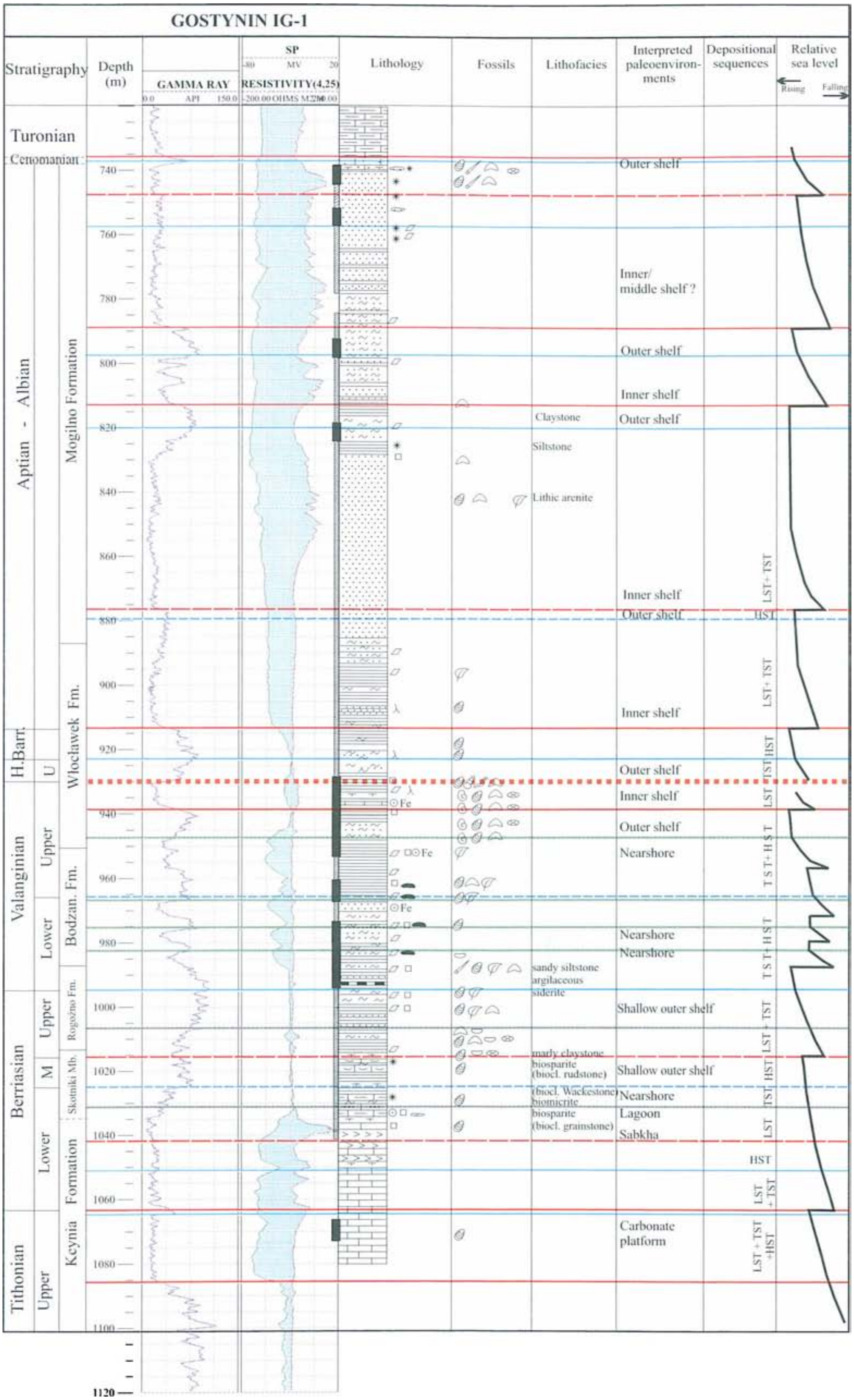


Fig. 33. Summary chart for the Lower Cretaceous in Gostynin IG 4. For explanation see Fig. 44



Summary chart for the Lower Cretaceous in Gostynin IG-1. For explanation see Fig. 44