

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

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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 referred 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-crusus*, *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. franki*. 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 nanofossils, depositional systems, sequence stratigraphy, Lower Cretaceous, central and southeastern Poland.

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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 Annapol 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 dis-

cussed 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 nanofossils. 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.

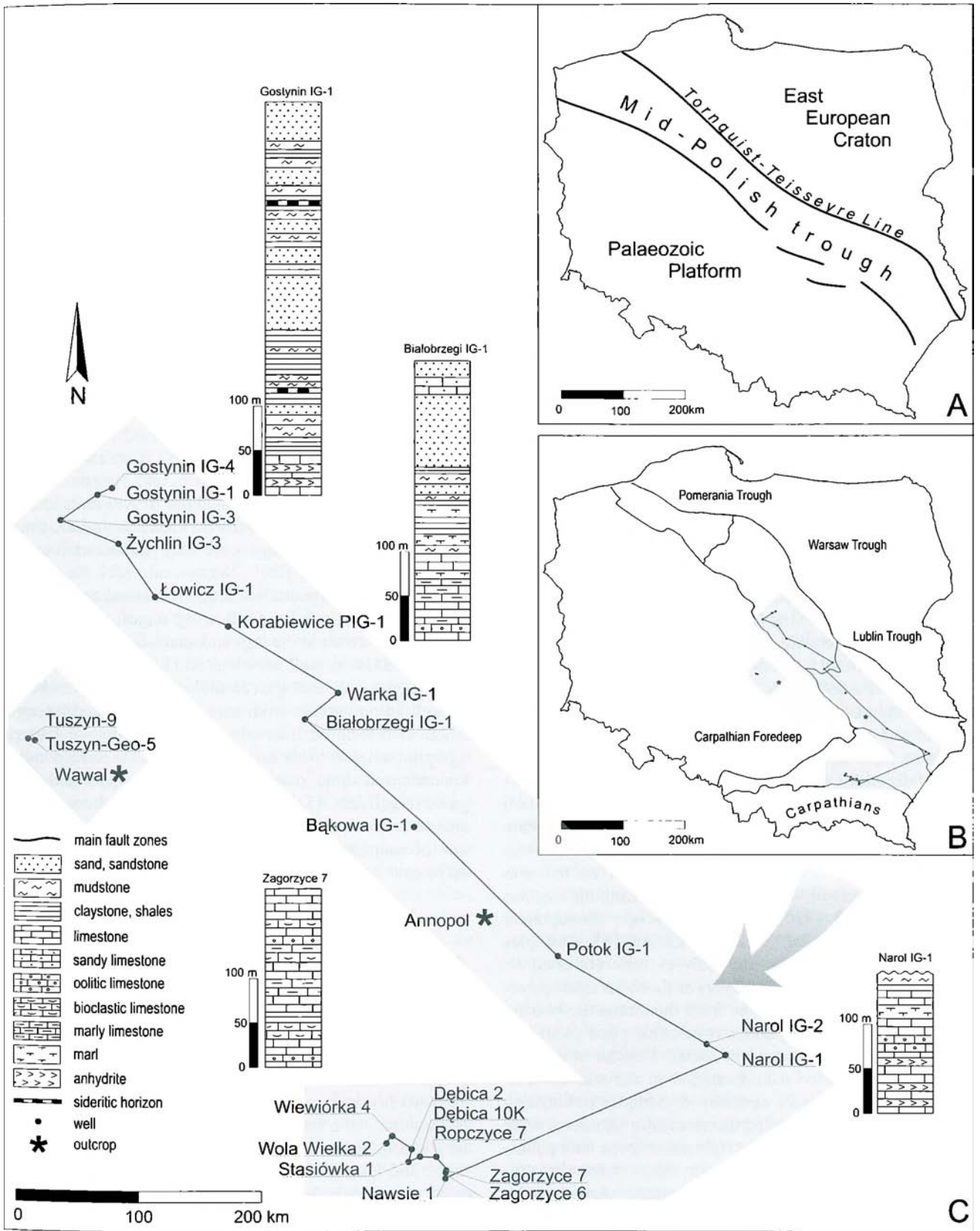


Fig. 1. A. Palaeotectonic map of Poland showing the main structural elements within the Polish Basin. B. Location of the studied area relative to the present-day tectonic units. C. Location of studied boreholes, outcrops and correlation profiles of lithology of the Lower Cretaceous within the studied 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. Marciniowski, A. Radwański, C. Kulicki, J. Kutek, J. Dzik, A. Kaim, T. Praszkiér and K. Dembiecz. The specimens from the J. Dzik's collection are labelled – ZPAL Am IX, those from the K. Dembiecz and T. Praszkiér's collection – x, while the collections of C. Kulicki, J. Kutek, R. Marciniowski, 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 Annapol were analysed because of expected correlation of nan-

noplankton 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 Annapol 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 & Raczynska, 1973; Marek *et al.*, 1989; Marek & Rajska, 1997; Kutek *et al.*, 1989; Marciniowski & Wiedmann, 1985, 1990), whereas stratigraphy of the Lower Berriasian, that includes Purbeckian facies lacking ammonites, was based on ostracods (Bielecka & Szejn, 1966; Marek *et al.*, 1989). Micropalaeontological methods were also applied to the younger Lower Cretaceous sequences (Moryc & Waśniowska, 1965; Kubiatowicz, 1983; Szejn, 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 Keynia 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 *Symbirsites*”) 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 Kruszewica 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 Trough, 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 oolitic 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 Białołbrzegi 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).

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 zonation 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-*

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

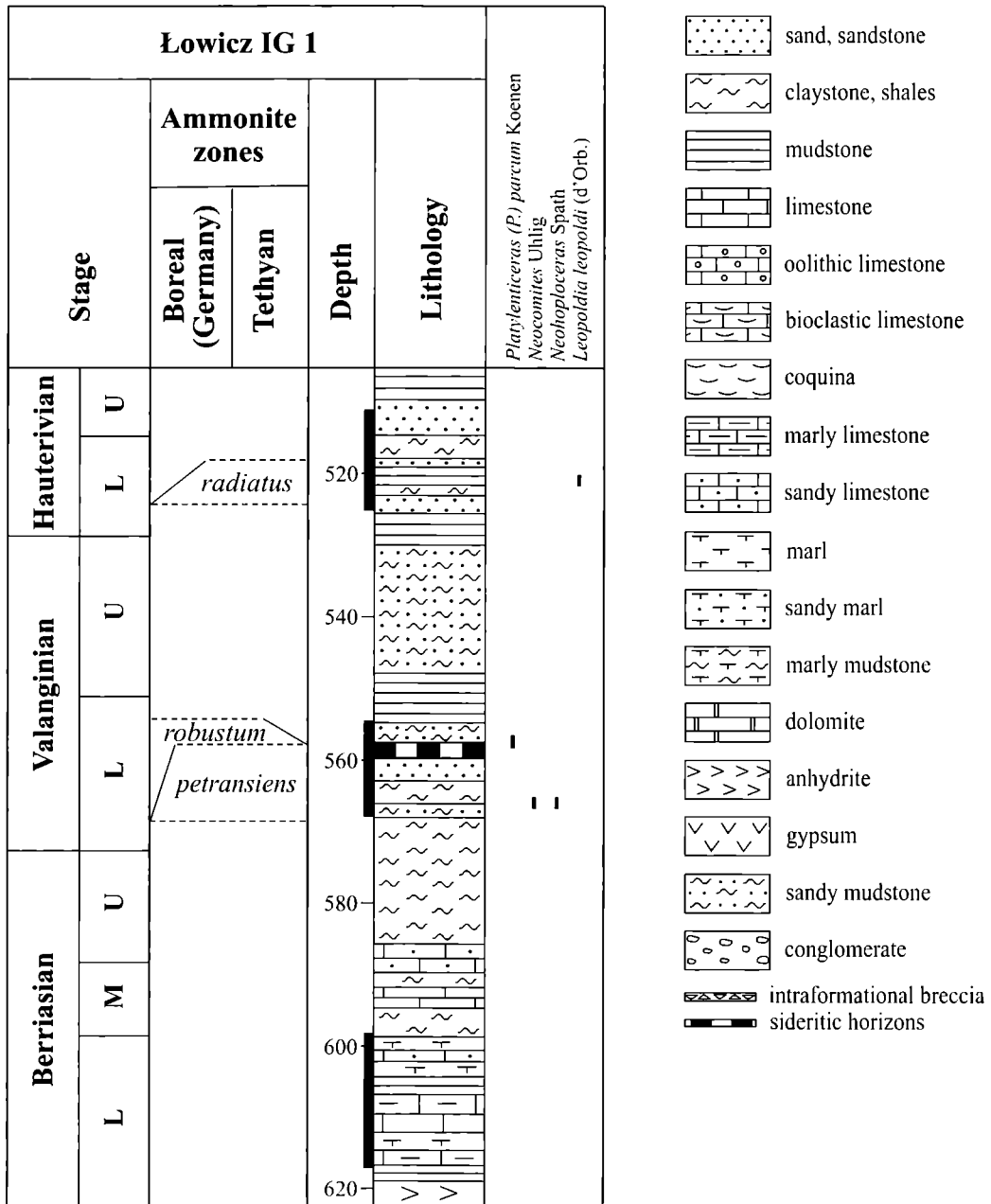


Fig. 2. Distribution chart of ammonites in the Lower Cretaceous deposits of the Łowicz IG-1

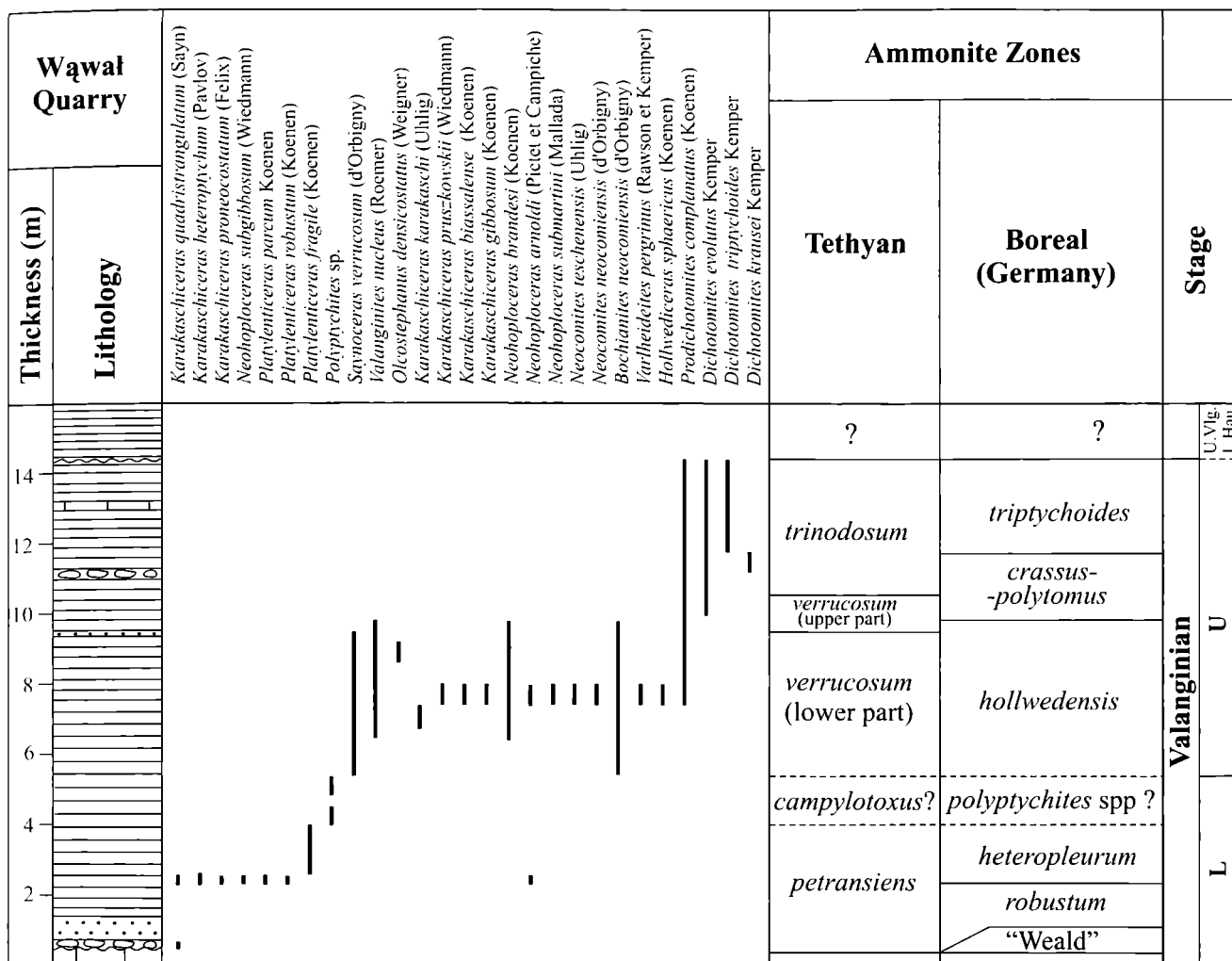


Fig. 3. Distribution chart of ammonites in the Lower Cretaceous deposits of the Wąwał clay-pit (after Kutek *et al.* 1989, Ploch this paper); for lithological description – see Fig. 2

ticeras”, and “Beds with *Surites*, *Euthymiceras* and *Neocosmoceras*” (Marek, 1964, 1968, 1969, 1977a, 1983, 1997; Marek & Raczynska, 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* (Uh-

lig) (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-*

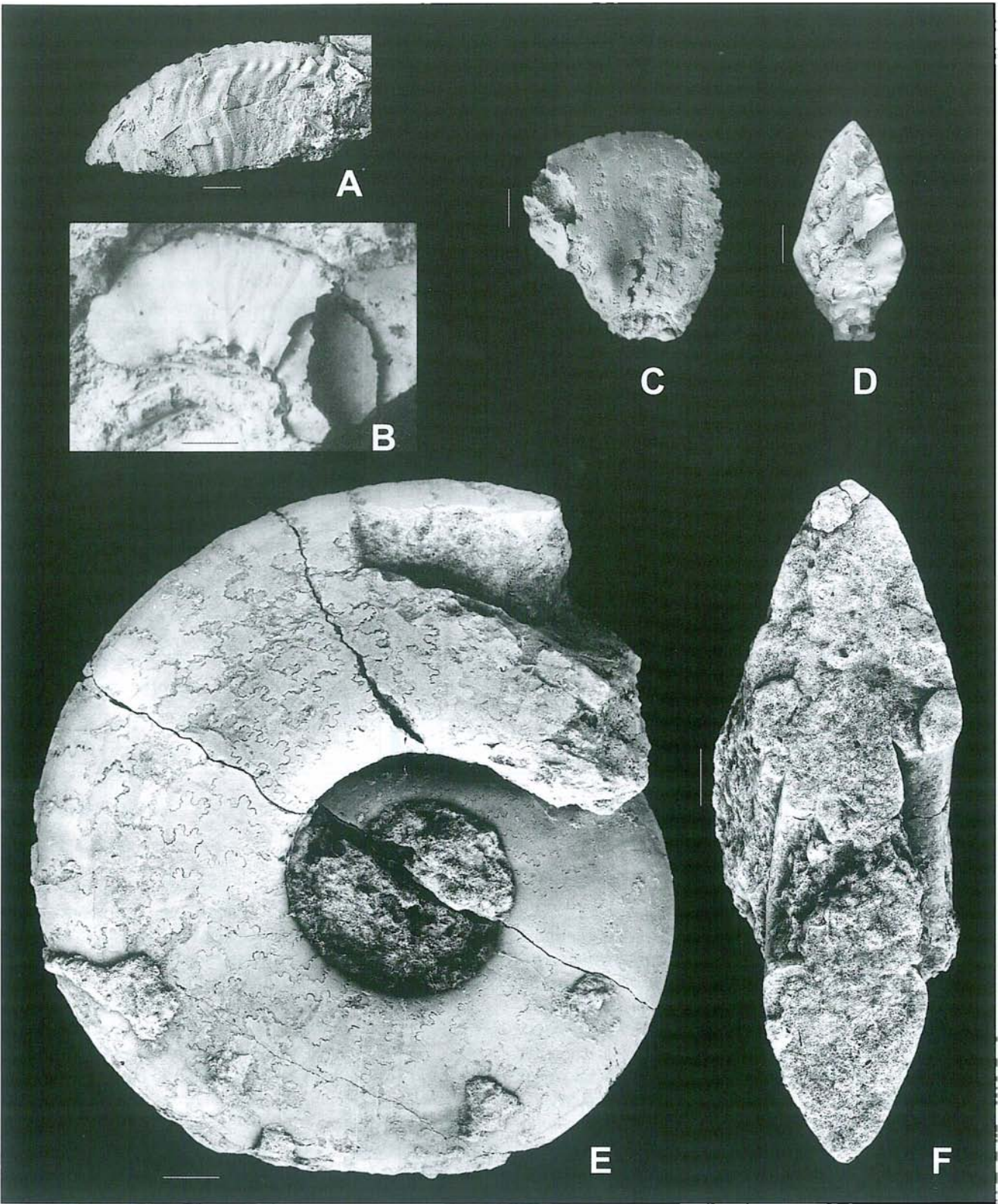


Fig. 4. A. *Acocomites* sp., nr 151P 11) Łowicz IG-1 (566.7 m), lower Volognian; B. *Neohopløeras* sp., nr 162P 11) 203. Łowicz IG-1 (566.8 m), lower Volognian; C, D. *Platylenticeras* (*Tolypceras*) *fragile* Koblenz, nr 161B XAW awa Łowicz; Volognian, *heteropleurum* Zöhe (O); ECF. *Platylenticeras* (*Platylenticeras*) *parcum parcum* Koblenz nr 171B XAW awa Łowicz; Volognian, *robustum* Zöhe. Scale bar - 47 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, *Karakaschicerias quadrirangulatum* (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. 51I, 1), *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 & Raczynska, 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, *Karakaschicerias quadrirangulatum* (Sayn), *Karakaschicerias heteroptychum* (Pawlow), *Karakaschicerias 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 *Karakaschicerias*, hitherto known from the Upper Valanginian, in the Tethyan Basin (Kutek *et al.*, 1989).

The “Beds with *Platylenticeras*, *Neocomites* and *Karakaschicerias*” 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 *Karakaschicerias*” 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-*

