



## The Lower Cretaceous depositional architecture and sedimentary cyclicity in the Mid-Polish Trough

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Six depositional systems have been recognized within the Lower Cretaceous deposits of the Mid-Polish Trough basing upon borehole data (cores, well logs). These are: (1) siliciclastic shelf system (with shallow and deep siliciclastic shelf sub-systems — the latter includes anoxic shelf facies), (2) deltaic system (prograding deltas), (3) fluvial system, (4) swampy-lacustrine system, (5) lagoonal system and (6) carbonate-clastic shelf system. They have facilitated

the recognition of two major sedimentary cycles — K1 and K2, which are subdivided into six minor ones of Late Berriasian through Middle Albian times. Cycle K1 begins with the Late Berriasian transgression. The beginning of cycle K2 is related to the Aptian transgression and increasing expansion of the Middle Albian basin. The Early Berriasian deposits terminate the latest Late Jurassic sedimentary cycle — J6-VII.

### INTRODUCTION

The paper concerns the depositional systems and sedimentary cyclicity in the Early Cretaceous epicontinental sedimentary basin of the Polish Lowlands. The reconstructed primary thickness of the Lower Cretaceous deposits (not decompacted) and extents of individual cycles are presented in a basinal framework map (S. Marek, A. Feldman *vide* S. Marek, 1988; modified by K. Leszczyński) (Fig. 1). The analysis has been essentially performed upon the basis of borehole data (cores, well logs). Of many boreholes which have been drilled over the whole territory of Poland, 13 boreholes have been examined in detail. These are the most characteristic, relatively well cored and with good quality well log record. Gamma ray, neutron-gamma ray and SP log curves have been used for purposes of depositional system analysis. Two of them (Figs. 2, 3) are shown as individual borehole sections with selected well log curves and interpreted depositional systems and cyclicity. A few selected boreholes are correlated along a line more or less perpendicular to the axis of the basin (Fig. 4). Schematic diagram showing the succession of depositional systems, relationships between them and the transgressive-regressive cycles is also shown (Fig. 5). The distribution of swampy-lacustrine and carbonate-clastic shelf systems have also been mapped (Figs. 6, 7).

For purposes of the present study, the results of previous lithological-stratigraphical, sedimentological and palaeontological investigations conducted for many years by a team of specialists have been used (S. Marek, 1967, 1969, 1983; A. Raczyńska, 1967, 1979; A. Witkowski, 1969; S. Marek, A. Raczyńska, 1979; J. Dadlez, R. Dadlez, 1987). It must be emphasized, however, that detailed sedimentological analyses require further investigations since those now available are, in many cases, insufficient for precise recognition of sedimentary environments and depositional systems. This is usually the case with fluvial and deltaic systems which have been distinguished basing merely upon general lithological features and well log analysis, not always yielding evidence for determining a particular depositional system.

Six depositional systems have been recognized. These are: (1) siliciclastic shelf system (with shallow and deep siliciclastic shelf sub-systems — the latter includes anoxic shelf facies), (2) deltaic system (prograding deltas), (3) fluvial system, (4) swampy-lacustrine system, (5) lagoonal system and (6) carbonate-clastic shelf system. They have been grouped into six transgressive-regressive cycles equivalent to 3rd order cycles of P. R. Vail *et al.* (1977) and comprising Late Berriasian through Middle Albian times (Tab. 1). These

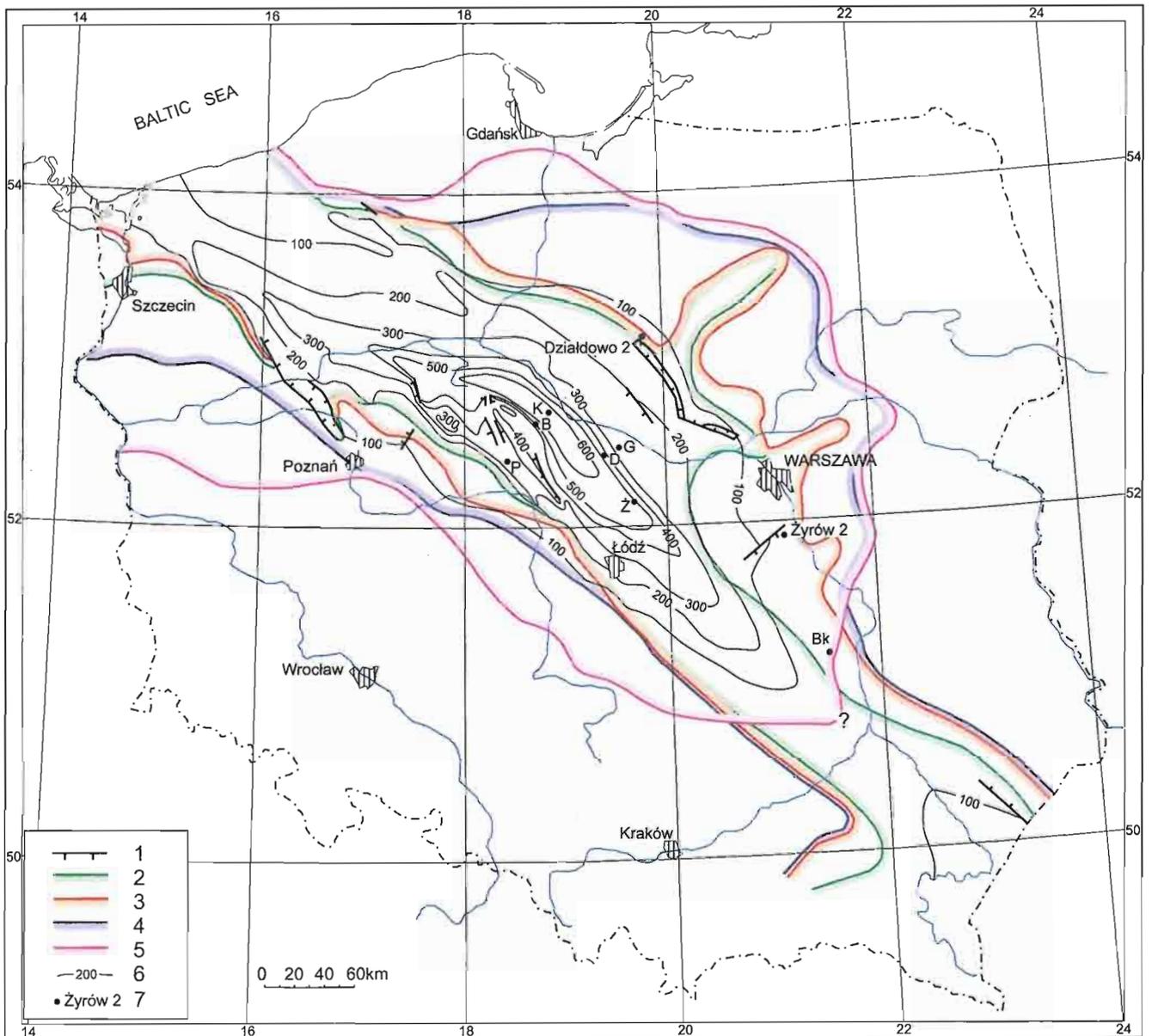


Fig. 1. Basinal framework of the Lower Cretaceous (excluding the Upper Albian) after S. Marek, A. Feldman (*vide* S. Marek, 1988), modified by K. Leszczyński

1 — synsedimentary faults; maximum extent of basin: 2 — Early Valanginian (*Platylenticeras*) (K1-I), 3 — Late Valanginian (K1-II), 4 — Hauterivian (K1-III), 5 — Middle Albian (K2-II); 6 — restored isopachs; 7 — interpreted borehole sections (B — Bodzanowo TK 10, Bk — Bąkowa IG 1, D — Dąbrówka TK 6, G — Gostynin 5, K — Kajetanowo TK 19, P — Pagórki IG 1, Ż — Żychlin)

Mapa paleotektoniczna kredy dolnej (bez albu górnego) według S. Marka, A. Feldman (*vide* S. Marek, 1988), uzupełniona przez K. Leszczyńskiego  
1 — uskoki synsedymantacyjne; maksymalne zasięgi basenów: 2 — walańżynu dolnego (*Platylenticeras*) (K1-I), 3 — walańżynu górnego (K1-II), 4 — hoterywu (K1-III), 5 — albu środkowego (K2-II); 6 — paleoizopachyty; 7 — interpretowane profile otworów wiertniczych (objaśnienia symboli otworów patrz tekst angielski)

cycles constitute, in turn, two major cycles spanning Late Berriasian to Barremian (K1) and Aptian to Middle Albian times (K2). The former begins with the Late Berriasian transgression and is characterized by stronger differentiation of subsidence in various areas. The latter is related to the Aptian

transgression and increasing expansion of the Middle Albian basin with more uniform subsidence. The Early Berriasian deposits terminate the latest Late Jurassic sedimentary cycle — J6-VII.

Table 1

## Subdivision of the Lower Cretaceous and sedimentary cyclicity in Central Poland (stratigraphy after S. Marek, 1988)

| Chronostratigraphy |           | Lithostratigraphy                 |                 |  | Transgressive-regressive cycles                                       |
|--------------------|-----------|-----------------------------------|-----------------|--|---|
| Stage              | Sub-stage | Formation                         | Member          | Ammonite zones and beds with index ammonites                   |   |
| Albian             | Upper     | Mogilno                           | Kruszwica (C)   | <i>Stoliczkaia dispar</i>                                      | K3-I  |
|                    | Middle    |                                   |                 | <i>Mortoniceras inflatum</i>                                   | K2-II   |
|                    | Lower     |                                   |                 | <i>Hoplites dentatus</i>                                       |   |
| Aptian             |           |                                   | Gopło (B)       | K2-I   |   |
| Barremian          |           |                                   | Pagórki (A)     |  |   |
| Hauterivian        | Upper     | Włocławek (Białobrzegi/Cieszanów) | Żychlin         | <i>Simbirskites</i>  | K1-IV   |
|                    | Lower     |                                   | Gniewkowo       | <i>Endemoceras</i>   |   |
| Valanginian        | Upper     | Bodzanowo                         | Wierzchosławice | <i>Dichotomites</i> and <i>Saynoceras</i>                      | K1-II   |
|                    | Lower     |                                   | Rogoźno         | Opozki   | <i>Platylenticeras</i> , <i>Neocomites</i> and <i>Karakaschiceras</i> |
| Berriasian         | Upper     | Zakrzewo                          |                 | <i>Riasanites</i> , <i>Himalayites</i> and <i>Picteticeras</i> |   |
|                    | Lower     | Kcynia                            | Kajetanowo      |  | J6-VII  |
|                    |           |                                   | Skotniki        |  |   |

## PALAEOTECTONIC BACKGROUND

The epicontinental Early Cretaceous sedimentary basin was strictly associated with the narrow Mid-Polish Trough (Fig. 1). Its central part (Kujawy region) displayed the strongest subsidence (S. Marek, 1988). Sedimentary continuity between the Upper Jurassic and Lower Cretaceous is observed there and the Lower Cretaceous deposits reach 650 m in thickness (S. Marek, 1988, 1997). On both flanks of the Mid-Polish Trough the thickness gradually decreases towards the north-east and south-west. There are considerable stratigraphical gaps and condensations in those areas.

Synsedimentary grabens of stronger subsidence related to block tectonics developed locally on both sides of the Mid-Polish Trough. They are characterized by a more complete lithological-stratigraphical sections of increased thicknesses. The central part of the trough exhibited the Early Cretaceous mobility related to salt movements and activity of synse-

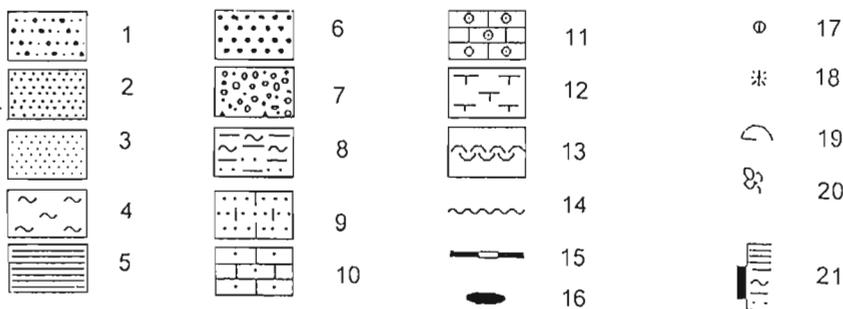
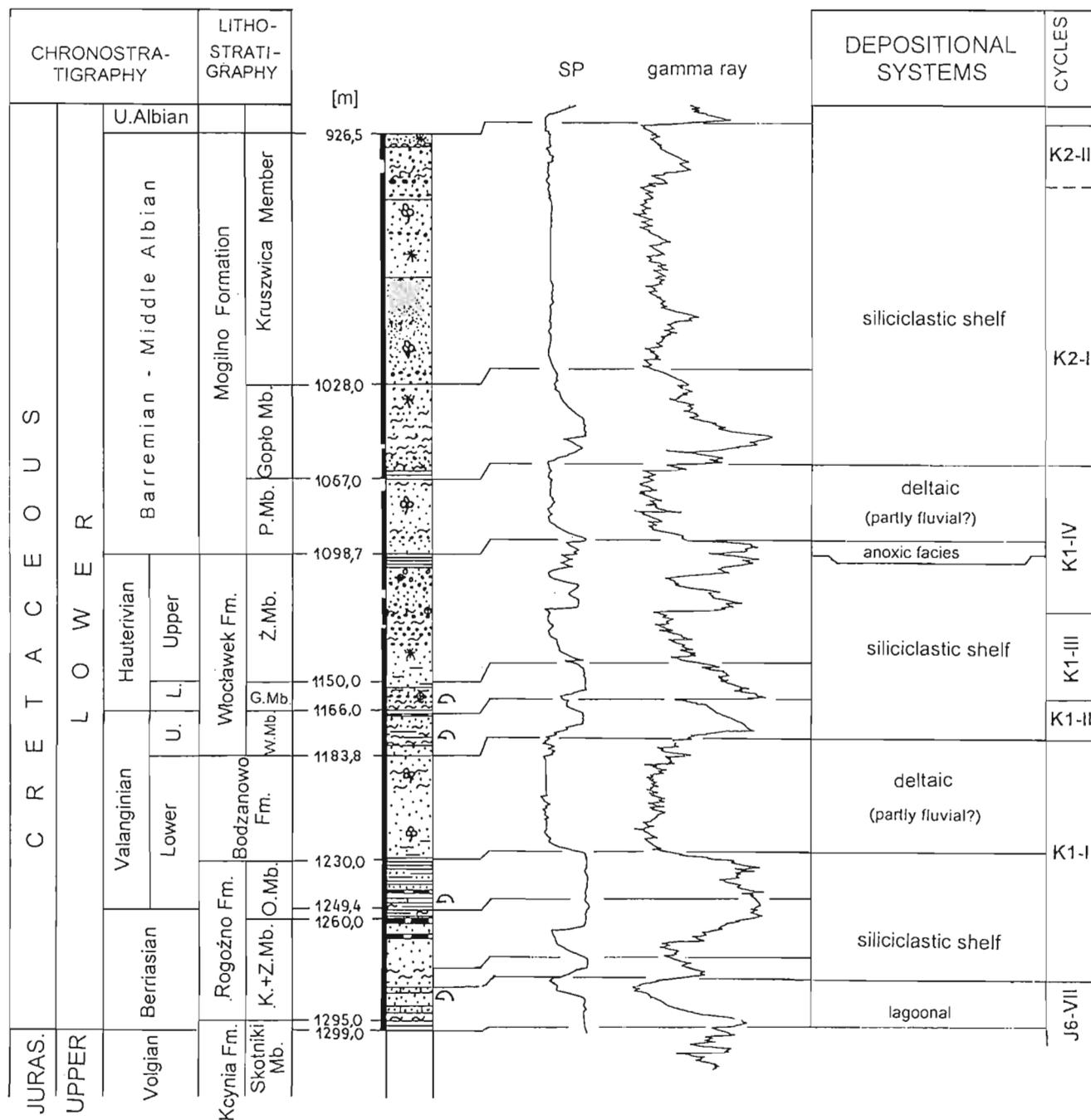
dimentary faults. Those resulted in a formation of a number of tectonic structures such as horsts, half-horsts, domes and elevations accompanied by depressions.

The epicontinental Early Cretaceous basin in Poland was increasing its extent beginning from the Late Berriasian through Hauterivian with a remarkable regression in the late Early Valanginian. It is interpreted that during the Barremian a considerable regressive event took place (A. Raczyńska, 1979; S. Marek, 1988). In the southeastern extension of the Mid-Polish Trough (Małopolska Massif), uplifting movements occurred at that time (A. Raczyńska, 1979). This resulted in separation of the basin from the Tethys by the Lower San Elevation. In Aptian–Middle Albian time the basin expansion towards SW and NE commenced again (S. Marek, 1988, 1997).

## STRATIGRAPHY

For correlation purposes, lithostratigraphic units established by A. Raczyńska (1979) and S. Marek (*vide* S. Marek, A. Raczyńska, 1979) and recently slightly modified by S. Marek (1997) are commonly in use (Tab. 1). They are particularly useful for marginal parts of basin where fossils are lacking and the lithostratigraphical method basing upon cores and well logs is the only one available. The biostratigraphic subdivision of the Lower Cretaceous (Tab. 1) is based on

ammonites largely from Pomerania and Kujawy (S. Marek, 1967, 1997; S. Marek, A. Raczyńska, 1979; S. Marek, M. Rajska, 1997). In the Berriasian, Valanginian and Hauterivian, informal stratigraphical units with index ammonite genera have been distinguished. For the Middle Albian deposits of the Holy Cross Mts., ammonite zones have been established. In the earliest Berriasian, ostracods play an important role (ostracod zone A). The Barremian, Aptian and Lower



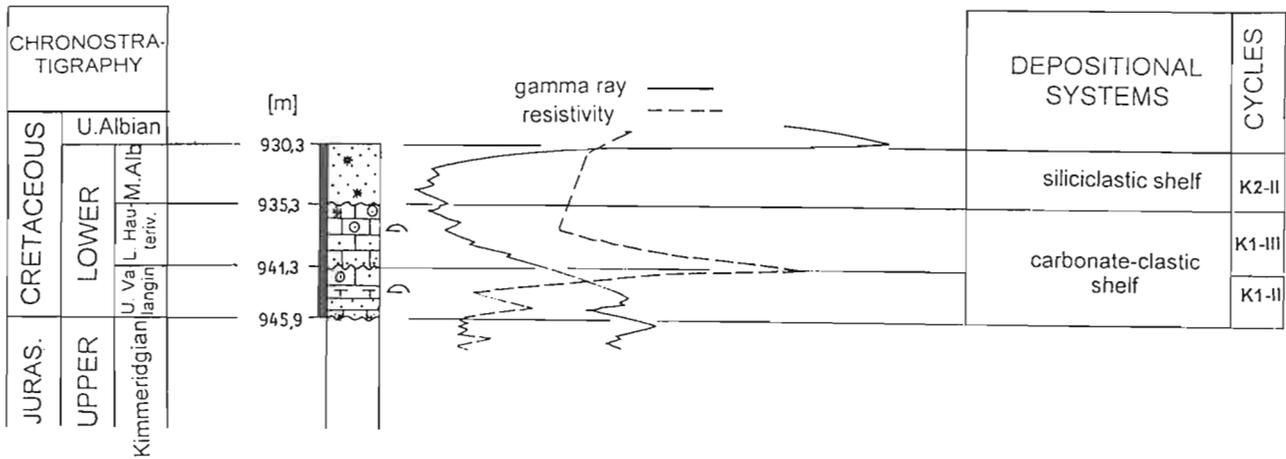


Fig. 3. Lower Cretaceous depositional systems and cyclicity in the Bąkowa IG 1 borehole section  
For explanations see Fig. 2

Systemy depozycyjne i cykliczność w kredzie dolnej w otworze Bąkowa IG 1  
Objaśnienia na fig. 2

Albian deposits do not yield any stratigraphically important fossils and their chronostratigraphical affiliation is based upon correlations with transgressive-regressive events observed in the German, Danish and Russian epicontinental

basins (A. Raczynska, 1979). Detailed biostratigraphical discussion and correlation with the standard division is presented by S. Marek (1997) and S. Marek, M. Rajska (1997).

## DEPOSITIONAL SYSTEMS

### SILICICLASTIC SHELF SYSTEM

Siliciclastic shelf system (with two sub-systems of shallow shelf and deep shelf) seems to be dominant in the Lower Cretaceous (Figs. 2, 4 and 5). It is represented in all the sedimentary cycles of all the borehole sections studied. In most cases the sedimentary cyclicity demonstrates a repeated, coarsening upward succession from deep shelf deposits (rapid transgression and deepening) to gradually shallower-marine facies. Sometimes, however, it is a simple succession from shallow shelf deposits passing into deeper shelf ones (slow transgression and deepening) and then into shallow shelf

deposits again. The whole Lower Cretaceous section can be subdivided into a few such sedimentary cycles within which siliciclastic shelf depositional system is the only one distinguishable.

Shallow siliciclastic shelf depositional sub-system is represented by light grey and grey, fine- to medium-grained sandstones, moderately or well sorted, largely of a quartz wacke or arenite type. Sandstone-siltstone-mudstone heteroliths and siltstones, occasionally marly and sideritic with glauconite and Fe-oolites also occur. The ferruginous oolites concentrations, locally abundant, might have been related to river estuaries. Carbonate sediments represented by marly,

Fig. 2. Lower Cretaceous depositional systems and cyclicity in the Pagórki IG 1 borehole section

1 — shales and claystones, 2 — siltstones, 3 — very fine- and fine-grained sandstones, 4 — medium-grained sandstones, 5 — unequigranular sandstones, 6 — coarse-grained sandstones, 7 — gravel and conglomerates, 8 — argillaceous siltstones and sandstones, 9 — calcareous sandstones, 10 — sandy limestones, 11 — oolitic limestones, 12 — marls, 13 — coquina, 14 — erosional surfaces, 15 — sideritic horizons, 16 — sideritic concretions, 17 — ferruginous oolites, 18 — glauconite, 19 — bivalves, 20 — flora remains, 21 — cores; K. + Z. Mb. — Kajetanowo Member + Zakrzewo Member, O. Mb. — Opoczki Member, W. Mb. — Wierzchosławice Member, G. Mb. — Gniewkowo Member, Ż. Mb. — Żychlin Member, P. Mb. — Pagórki Member

Systemy depozycyjne i cykliczność w kredzie dolnej w otworze Pagórki IG 1

1 — łupki ilaste i iłowce, 2 — mułowce, 3 — piaskowce bardzo drobno- i drobnoziarniste, 4 — piaskowce średnioziarniste, 5 — piaskowce różnoziarniste, 6 — piaskowce gruboziarniste, 7 — żwiry i zlepiańce, 8 — piaskowce i mułowce ilaste, 9 — piaskowce wapieniste, 10 — wapienie piaszczyste, 11 — wapienie oolitowe, 12 — margle, 13 — muszłowce, 14 — powierzchnie erozyjne, 15 — poziomy syderytyczne, 16 — konkretje syderytyczne, 17 — oolity żelaziste, 18 — glauconit, 19 — małże, 20 — uwęglone szczątki roślin, 21 — odcinki rdzeniowane; K. + Z. Mb. — ogniwo kajetanowskie + ogniwo zakrzewskie, O. Mb. — ogniwo z Opoczki, W. Mb. — ogniwo wierzchosławickie, G. Mb. — ogniwo gniewkowskie, Ż. Mb. — ogniwo żychlińskie, P. Mb. — ogniwo pagórczańskie

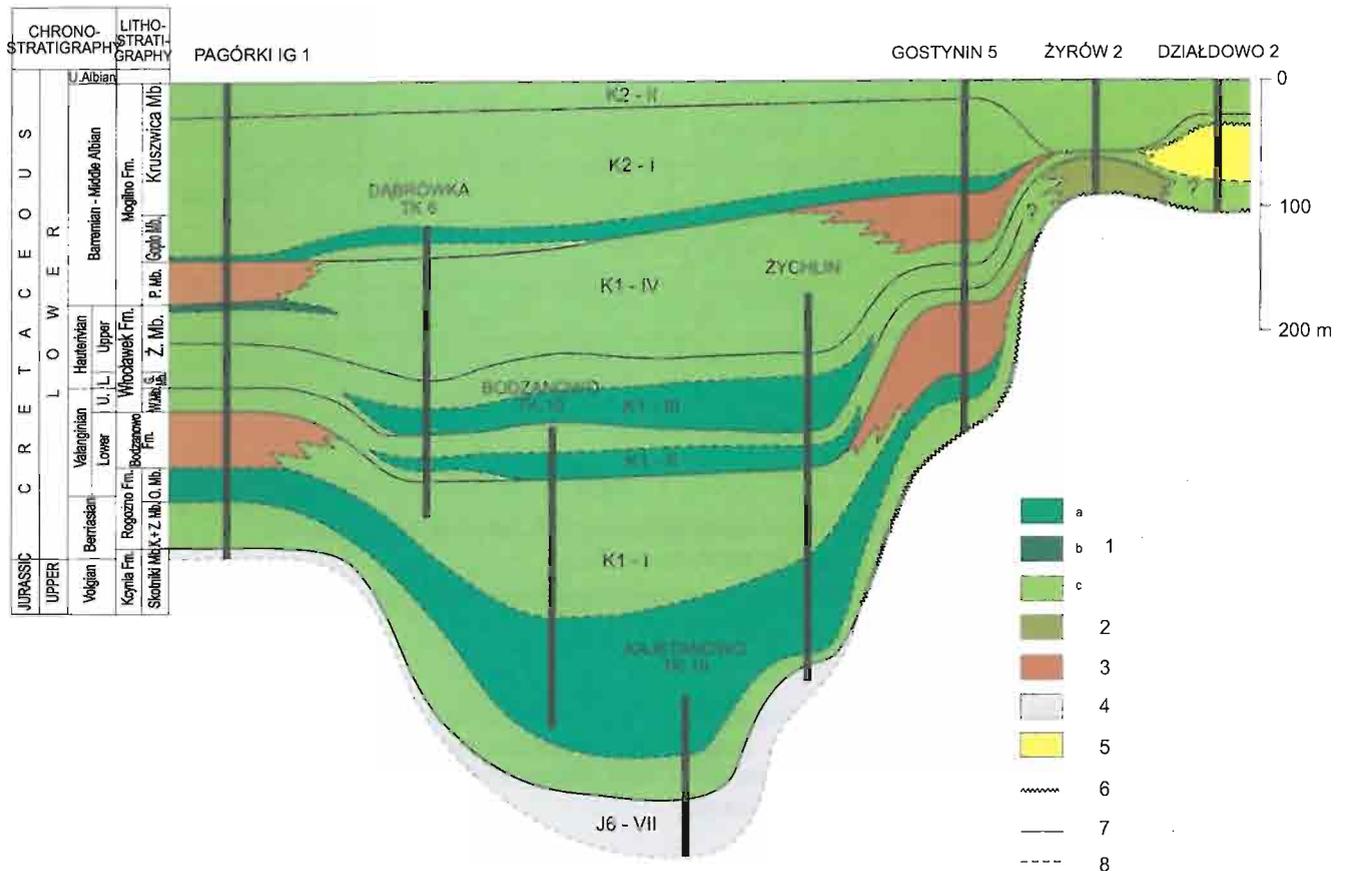


Fig. 4. Correlation of depositional systems and transgressive-regressive cycles between selected boreholes in the Lower Cretaceous sequences of Central Poland

1 — siliciclastic shelf system (a — deep shelf, b — anoxic shelf facies, c — shallow shelf); 2 — carbonate-clastic shelf system; 3 — deltaic system; 4 — lagoonal system; 5 — fluvial system; 6 — erosional surfaces; 7 — boundaries between transgressive-regressive cycles; 8 — boundaries between depositional systems

Korelacja systemów depozycyjnych i cykli transgresywno-regresywnych dolnej kredy centralnej Polski w wybranych otworach wiertniczych

Systemy depozycyjne: 1 — szelfu klastycznego (a — głębokiego, b — facje szelfu anoksydacyjnego, c — płytkiego); 2 — szelfu węglanowo-klastycznego; 3 — deltowy; 4 — lagunowy; 5 — fluwialny; 6 — powierzchnie erozyjne; 7 — granice cykli transgresywno-regresywnych; 8 — granice systemów depozycyjnych

calcareous and sandy dolomite intercalations have been noted in the Lower Berriasian and Upper Hauterivian of the Kujawy region. Shallow shelf deposits are usually laminated, cross-, horizontally-, flaser- and lenticular-bedded, mostly bioturbated with vertical burrows and plant remains. Ostracods, foraminifers and bivalves composing thin coquina layers are the most common faunal elements. Ammonites, brachiopods, gastropods and belemnites have also been reported. The described sediments were deposited in an open-marine environment of a shallow, near-shore, sub-littoral zone, above the wave base, at a water depth of a few metres to several tens of metres.

Deep siliciclastic shelf depositional sub-system is essentially represented by medium grey and dark grey shales and claystones, occasionally marly or sideritic, laminated and thin-bedded with intercalations of siltstones and fine-grained sandstones. They are usually bioturbated (strongly in places) with predominant horizontal burrows and yield abundant fossils: foraminifers, ostracods, bivalves, ammonites, belemnites and brachiopods.

These sediments were deposited in a deeper, sub-littoral zone, below the wave base, at a depth of several tens of metres (up to 100 m) in open-marine and relatively quiescent environments of the central parts of the basin.

Anoxic facies are represented by black non-calcareous and non-bioturbated laminated claystones and shales. Pyrite is a very characteristic and common mineral (dispersed or agglomerated). Sphaerosiderites are also frequent. These deposits are characterized by the complete lack of benthic fauna and the increased bitumen and other organic matter content. They were deposited under reducing conditions in zones of local deepening, with specific topography of the sea bottom and restricted water circulation, mainly related to synsedimentary grabens. Anoxic facies may have been deposited, depending upon the sea bottom configuration, in various bathymetric conditions ranging from several tens of metres up to 100 m and locally even more. These facies have been reported for example from the Upper Hauterivian (Żychlin Member) of the Szamotuły and Gopło regions (A. Raczyńska,

1979). They always show a high positive gamma-ray anomaly on well logs (Figs. 2, 4 — borehole Pagórki IG 1).

#### DELTAIC SYSTEM (PROGRADING DELTAS)

This system is represented by coarsening upward clastic sequences (delta slope?) succeeded in the upper part by fining upward (delta plain?) or massive complexes (distributary channel, crevasse?). In many sections the upper part is lacking.

Deltaic system is mostly composed of non-calcareous sandstones with gravel horizons, locally with abundant muscovite flakes. Plant remains as well as coal-clayey laminae are frequent. Lower parts of deltaic sandstone sequences may be intercalated with siltstones and mudstones locally sideritic and dolomitic, bioturbated in places, with scarce predominantly marine bivalve fauna and glauconite. These deposits are parallel or cross-bedded with flaser and lenticular lamination.

On well logs, a prograding delta sequence is characterized in the lower part by a complex of decreasing upwards and serrated gamma ray and SP curves and above by one or more complexes of increasing upwards or stable values (Fig. 2). Such a well log record supported by good quality core material is essentially sufficient to distinguish deltaic sequences. In many cases, however, there are much difficulties in distinguishing between prograding delta and prograding marine shelf deposits (siliciclastic shelf system).

Deltaic system represents a regressive phase (late stage of highstand) when greater amounts of clastic material were shed from surrounding lands into the basin and deposited in the form of prograding deltas. Therefore, it appears above siliciclastic shelf depositional system and usually occurs together with the overlying fluvial depositional system (Figs. 2, 4 and 5). Deltaic deposits in the Lower Cretaceous sequences reach a few tens of metres in thickness.

Within the Lower Cretaceous sequences, either the entire Bodzanowo Formation (upper Lower Valanginian, *Polyptychites* Beds) and Pagórki Member (corresponding to the Barremian) or at least their lower parts, have been considered to be deltaic (Fig. 2). Some sediments of the lower part of the Kruszewica Member (corresponding to the Lower Valanginian?) can also represent deltaic environments.

#### FLUVIAL SYSTEM

This system is represented by white, light grey and yellowish, very fine- to coarse-grained non-calcareous quartz sandstones. They show a variable sorting — from poor to fairly well. The matrix is frequently rich in Fe-hydroxides and kaolinite. Parallel-laminated silty and clayey intercalations as well as heteroliths have been noted. No glauconite has been observed. Gravel horizons and plant and wood remains are abundant. Tabular and presumably trough cross bedding are the most common sedimentary structures in the sandstones. Erosional surfaces covered by gravel horizons are also fre-

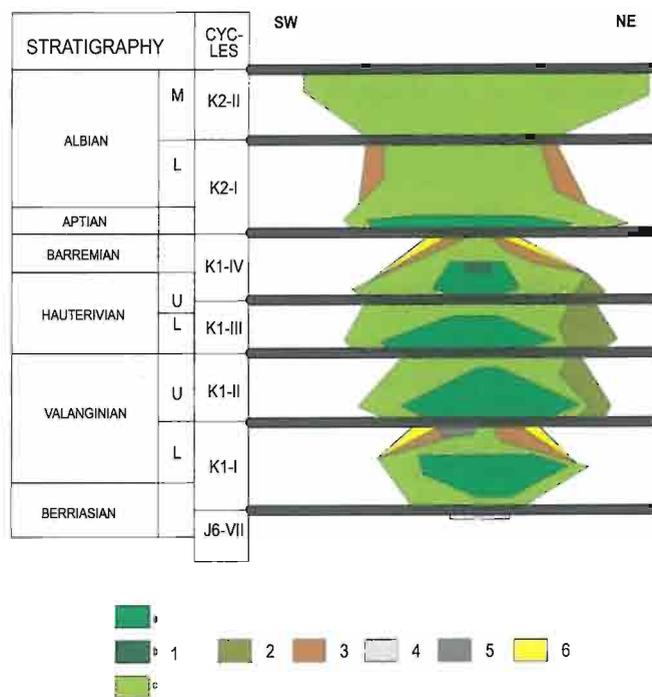


Fig. 5. Schematic diagram showing the succession of the Lower Cretaceous depositional systems along the line perpendicular to the basin depocenter 1 — siliciclastic shelf system (a — deep shelf, b — anoxic shelf facies, c — shallow shelf); 2 — carbonate-clastic shelf system; 3 — deltaic system; 4 — lagoonal system; 5 — swampy-lacustrine system; 6 — fluvial system

Schematyczny przekrój obrazujący następstwo systemów depozycyjnych w dolnej kredzie

Systemy depozycyjne: 1 — szelfu klastycznego (a — głębokiego, b — facje szelfu anoksycznego, c — płytkiego); 2 — szelfu węglanowo-klastycznego; 3 — deltowy; 4 — lagunowy; 5 — bagienno-jeziorny; 6 — fluwialny

quent. No marine fossils have been collected from these deposits. Fluvial system has been recognized above deltaic system in the upper part of the Pagórki Member (corresponding to the Barremian). Its upper boundary is marked by the appearance of typically marine, transgressive deposits of the Gopło Member (corresponding to the Aptian) with glauconite and marine fauna. It is likely that part of the upper Lower Valanginian sequence (*Polyptychites* Beds) so far considered to belong to deltaic depositional system represents in fact fluvial environment and thus fluvial depositional system. Some sediments of the lower part of the Kruszewica Member (corresponding probably to the Lower Valanginian?) are also suggestive of both fluvial and deltaic environments. Unquestionable environmental interpretation is still difficult because of lack of detailed sedimentological investigations. Fluvial deposits seem to reach a few tens of metres in thickness.

Fluvial system often terminate sedimentary cycles, representing their regressive members (Figs. 4, 5). It has been distinguished basing upon general lithological features and the shape of well log curves, not always providing a univocal information for precise determination of depositional environments. The Lower Cretaceous coarse-grained clastics, devoid of both glauconite and any faunal elements but rich in

plant fragments, require further detailed sedimentological studies in order to recognize ultimately their depositional environment and the affiliation to a particular depositional system.

#### SWAMPY-LACUSTRINE SYSTEM

This system is represented by grey (brownish in places), non-calcareous sandy-silty-clayey sediments, a few metres up to several tens of metres thick. They are commonly parallel-laminated with clayey-coal laminae. Rhizoid facies with abundant coalified wood fragments and other plant remains are frequent (e.g. Szamotuły region). These deposits have yielded no faunal fossils. They were deposited in a vast, very shallow (up to a few metres deep) and fresh-water lakes with shoals and swamps (A. Raczyńska, 1967).

Swampy-lacustrine deposits have been recognized only in the northwestern part of Poland (Fig. 6) in the late Lower Valanginian (upper part of the *Polyptychites* Beds) and comprise the uppermost part of the Bodzanowo Formation. They overlie prograding delta facies and fluvial deposits and correspond to the maximum regression and shallowing of the basin preceding the Late Valanginian transgression (Fig. 5). On well logs they are characterized by slightly higher gamma ray values (related to higher clay content) as compared with the underlying deltaic deposits. Above, gamma ray values gradually increase reflecting the fining upward sequence of the Late Valanginian transgression.

#### LAGOONAL SYSTEM

This system is represented by small thickness (up to 40 m), brackish and brackish-marine shallow-water deposits (S. Marek, 1967, 1969). The most common lithologies are grey laminated and thin-bedded calcareous sandstones, siltstones and claystones, occasionally with marl and limestone intercalations as well as thin coquina layers. They are frequently rich in fossils of mainly gastropods, ostracods, foraminifers. Plant remains are abundant in places. Faunal assemblages indicate brackish and brackish-marine lagoonal environment with water depth of a few metres (S. Marek, 1969). Lagoonal

deposits have been recognized in the Early Berriasian and they terminate the latest Late Jurassic sedimentary cycle J6-VII (Figs. 2, 4 and 5) comprising (according to recently accepted lithostratigraphical subdivision of S. Marek, A. Raczyńska, 1979) the uppermost part of the Skotniki and Kajetanowo Members (Tab. 1). They occur in the central zone where the continuity between the Upper Jurassic and Lower Cretaceous is marked (S. Marek *et al.*, 1989). Lagoonal system has been distinguished below the first well pronounced Early Cretaceous transgressive event (cycle K1-I) with typical marine deposits.

#### CARBONATE-CLASTIC SHELF SYSTEM

This system has been recognized in the southeastern part of the Late Valanginian and Hauterivian basin and extends more or less from Warsaw towards the south-east (S. Marek, 1983; W. Moryc, J. Waśniowska, 1965; S. Kijakowa, W. Moryc, 1991) (Fig. 7). It is generally correlated with the Białobrzegi/Cieszanów Formation established for this part of the Early Cretaceous basin.

This system is represented by carbonate deposits of small thickness (from a few up to several tens of metres), with a variable content of terrigenous clastic material, mostly sandy, occasionally with glauconite (Fig. 3). These are organodetrital limestones, oolitic limestones, marls and silty marls. The limestones are of oomicritic, oobiomitic or biomicritic types. They yield a variety of fossils: mostly echinoderms, bivalves, bryozoans, ammonites, brachiopods, and foraminifers. The limestones are frequently intercalated with marly claystones, siltstones and sandstones. These sediments were deposited in a shallow-marine environments (up to a few tens of metres deep).

Carbonate-clastic shelf depositional system occurs in the areas where the basin configuration, low topography of surrounding lands, suitable climatic conditions and inflow of well oxygenated warm waters from the Tethys resulted in the formation of carbonate facies rich in organic life. This system seems to develop contemporaneously with shallow siliciclastic shelf system extending over the remaining part of the basin at those times (Figs. 5, 7).

### THE TRANSGRESSIVE-REGRESSIVE CYCLES

Two major transgressive-regressive cycles (K1 and K2) comprising six minor cycles have been recognized in the Lower Cretaceous. The Early Berriasian deposits terminate the latest Late Jurassic sedimentary cycle — J6-VII. Transgressive-regressive cycles recognized in Central Poland are compared with the eustatic curve of B. U. Haq *et al.* (1988) in Figure 8. The maximum high stands of sea-level occurred

during the earliest Early Valanginian (Opoczki Member), early Late Valanginian, Early Hauterivian, middle (latest?) Late Hauterivian, Aptian and Middle Albian. The lowest stands of sea-level were during the Early Berriasian (Skotniki and Kajetanowo Members), late Early Valanginian, latest Late Valanginian, early Late Hauterivian, Barremian and Early Albian.

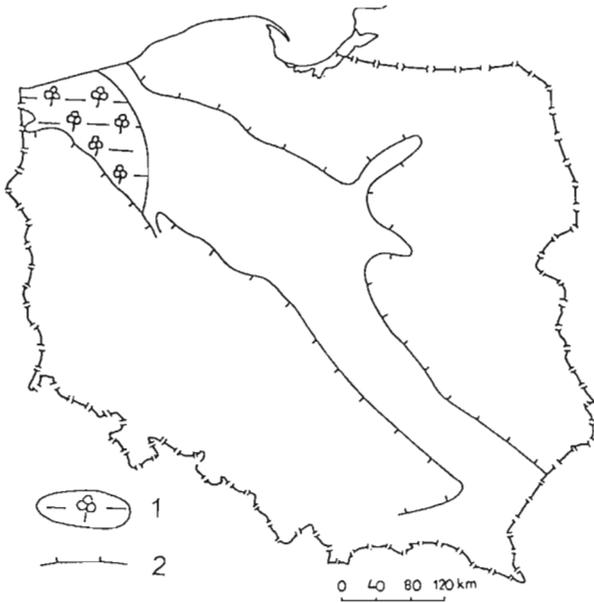


Fig. 6. Distribution of swampy-lacustrine system in the late Early Valanginian basin

1 — swampy-lacustrine deposits; 2 — primary extent of the late Early Valanginian basin (after S. Marek, 1988)

Występowanie systemu bagiennie-jeziornego w basenie późnego dolnego walażynu

1 — utwory bagiennie-jeziorne; 2 — pierwotny zasięg basenu późnego dolnego walażynu (według S. Marka, 1988)

#### J6-VII — EARLY BERRIASIAN (UPPER PART OF THE SKOTNIKI MEMBER + KAJETANOWO MEMBER)

This is the latest Late Jurassic sedimentary cycle comprising also the Early Berriasian deposits. Its uppermost part consists of brackish-marine deposits (lagoonal depositional system) of the Skotniki and Kajetanowo Members (Tab. 1). This cycle has been recognized in the central zone in continuous Upper Jurassic–Lower Cretaceous sections. Its upper boundary is defined by the appearance of typically marine silty-sandy or calcareous-sandy deposits containing glauconite and marine fauna (Zakrzewo Member) which mark the onset of the Late Berriasian transgression. Towards both basin flanks a discontinuity between the Upper Jurassic and Lower Cretaceous is observed, thus the Lower Cretaceous sedimentation begins there with the K1-I marine deposits of the Zakrzewo Member overlying the older Upper Jurassic stratigraphical units (Fig. 4).

The ostracod zone A has been established within the Skotniki and Kajetanowo Members, corresponding to the *runctoni* Zone of the English division as well as the *jacobi* and *grandis* Zones of the Thetyan province. It contains ostracods *Cypridea posticalis* (Jones) and *C. obliqua polonica* Szejn regarded as guide fossils. The Zakrzewo Member corresponds to the *Riasanites*, *Himalayites* and *Picteticeras* Beds which are the equivalent to the *occitanica* Zone. These deposits yield a variety of ammonites such as *Beriasella* (*Picteticeras*) cf.

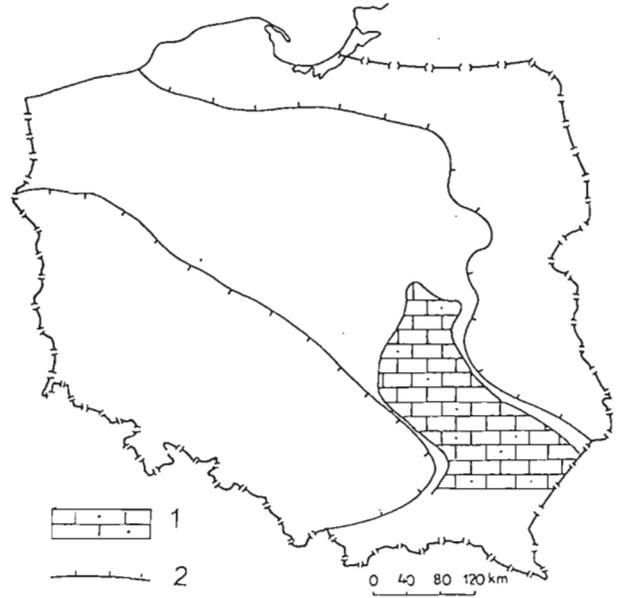


Fig. 7. Distribution of carbonate-clastic shelf system in the Hauterivian basin

1 — carbonate-clastic shelf deposits; 2 — primary extent of the Hauterivian basin (after S. Marek, 1988)

Występowanie systemu szelfu węglanowo-klastycznego w basenie hoterywu

1 — osady szelfu węglanowo-klastycznego; 2 — pierwotny zasięg basenu hoterywu (według S. Marka, 1988)

*picteti* (Jacobs), *Riasanites* cf. *swistowianus* (Nikitin), *R. rjasanensis* (Nikitin), *Himalayites* sp. and *Pseudosubplanites* (*Hegarotella*) cf. *jauberti* (Mazenot) (S. Marek et al., 1989; S. Marek, M. Rajska, 1997).

#### K1-I — LATE BERRIASIAN–EARLY VALANGINIAN (ZAKRZEWO + OPOCZKI MEMBERS + BODZANOWO FORMATION)

This cycle begins with shallow-marine transgressive sediments (shallow shelf deposits) of the Zakrzewo Member which pass upwards into deeper-marine dark grey and black shales (deep shelf deposits of the Opczki Member) (Tab. 1, Fig. 2). The overlying Bodzanowo Formation (late Early Valanginian) is considered to be a regressive phase of this cycle. It is expressed by a progradation of shallow-marine shelf deposits or prograding deltas (deltaic depositional system). Fresh-water environments (swampy-lacustrine and fluvial depositional systems) have also been described within the Bodzanowo Formation in some borehole sections. Within sandy deposits of the Bodzanowo Formation which is the equivalent of the *Polyptychites* Beds and corresponds to the *campylotoxum* Zone, a few specimens of *Polyptychites* cf. *gravidus* (Koenen) has been found. The upper boundary of cycle K1-I is marked by a sharp change in sedimentation from sandy to muddy. This heralds the Late Valanginian transgression. A still minor cycle reflecting a weak transgressive pulse can be seen within the Bodzanowo Formation in the central

part of the Early Valanginian basin. It is, however, suggested here to be a 4th order cycle.

K1-II — LATE VALANGINIAN (WIERZCHOSŁAWICE MEMBER — LOWER PART OF THE BIAŁOBRZEGI /CIESZANÓW FORMATION)

The lower boundary of this cycle is marked, as it was mentioned above, by the strong Late Valanginian transgression. Its range exceeds that of the previous one. The sediments rapidly pass up from sandy-silty into clayey. The upper part of cycle K1-II is pronounced by a considerable shallowing with sandstones becoming predominant. This cycle as a whole is represented by siliciclastic shelf system which is replaced in the south-east by carbonate-clastic shelf system (Figs. 3, 5 and 7). In the latter area cycles K1-II and K1-III are frequently impossible to separate within a complex of carbonate-clastic rocks. There are also some difficulties in separating these cycles in other regions. In the borehole section of Bąkowa IG 1 the two cycles are well seen on well log curves (Fig. 3) and the boundary between them can easily be drawn. Cycle K1-II consists here of organodetrital limestones overlain by sandy limestones of cycle K1-III. Within the Upper Valanginian clastic deposits, the *Dichotomites* and *Saynoceras* Beds have been established (Tab. 1). They contain abundant and diverse marine faunas represented among others by ammonites such as *Saynoceras verrucosum* (d'Orbigny), *Bochianites neocomiensis* (d'Orbigny), *Valanginites nucleus* (Roemer), *Karakaschiceras karakaschi* (Uhlig), *K. pruszkowskii* Kutek, Marcinowski et Wiedmann, *Neocomites teschenensis* (Uhlig), *Prodichotomites complanatus* (Koenen) and *Dichotomites evolutus* Kemper (S. Marek et al., 1989; S. Marek, M. Rajska, 1997). The upper boundary of cycle K1-II is defined by the first appearance of claystones and siltstones (*Endemoceras* Beds corresponding to the *radiatus*, *loryi* and *jeanoti* Zones) associated with the Early Hauterivian transgression. In the marginal parts, the boundary is marked by erosional surfaces and breaks in sedimentation. The Lower Hauterivian deposits frequently overlies in those areas various units of the Upper Jurassic.

K1-III — EARLY HAUTERIVIAN–EARLY LATE HAUTERIVIAN (GNIEWKOWO MEMBER + LOWER PART OF THE ŻYCHLIN MEMBER — BIAŁOBRZEGI /CIESZANÓW FORMATION)

The extent of this cycle oversteps that of the previous one. It begins with silty-clayey deposits which usually rapidly grade up into dark-coloured claystones followed by a regressive coarsening upwards sequence reflecting a shallow shelf progradation (shallow siliciclastic shelf system). Deeper-marine deposits of the *Endemoceras* Beds have yielded many specimens of bivalves and ammonites such as *Endemoceras* cf. *amblygonium* (Neumayr et Uhlig), *E. aff. enode* Thiermann and *E. sp.* (ex gr. *noricum-enode*) (S. Marek et al., 1989; S. Marek, M. Rajska, 1997). The marginal parts were the areas where deltaic and even fluvial sedimentation may have taken place but the record is lacking due to erosion. Carbonate-clastic shelf depositional system appears to con-

tinue in the south-east (Figs. 3, 5 and 7). The upper boundary of this cycle is drawn within the *Simbirskites* Beds (Tab. 1) with extremely scarce specimens of *Simbirskites* (*Craspedodiscus*) cf. *gottschei* (Koenen) which were found within clastic deposits of the uppermost part of cycle K1-III.

K1-IV — LATEST LATE HAUTERIVIAN–BARREMIAN (UPPER PART OF THE ŻYCHLIN MEMBER — UPPER PART OF THE BIAŁOBRZEGI /CIESZANÓW FORMATION + PAGÓRKI MEMBER)

Transgressive sandy-muddy deposits mark a considerable deepening of the sea and the onset of cycle K1-IV. These are open-marine sediments (Żychlin Member) of shallow siliciclastic shelf depositional system containing ammonite fauna in the Kujawy region. Graben zones were the areas of temporary anoxic conditions (anoxic shelf facies). The upper part of this cycle is composed of a sandy sequence. In the central part of the basin these are shallow shelf or prograding delta deposits. Elsewhere, over vast areas, the series is likely to represent fluvial environment corresponding to the maximum regressive stage (Figs. 4, 5). The sequence yields no faunal fossils. The upper, mostly erosional boundary of cycle K1-IV is sharp and marked by the appearance of open-marine, dark-coloured clayey sediments with glauconite and foraminifers attributed to the Aptian transgressive event.

K2-I — APTIAN–EARLY ALBIAN? (GOPŁO MEMBER + LOWER PART OF THE KRUSZWICA MEMBER)

This cycle begins with a rapidly progressing marine transgression (Figs. 4, 5). The lower series (Gopło Member) consists of dark grey and black shales and siltstones grading up into alternating claystone-siltstone-sandstone deposits and finally light-coloured sandstones (from deep to shallow shelf deposits). The upper series (lower part of the Kruszwica Member) is composed of poorly sorted sandstones with gravel (shallow shelf deposits). Part of them may represent deltaic or fluvial depositional systems. The sandstones are overlain by another sandy complex which begins with unequigranular and conglomeratic sandstones with abundant glauconite. These are related to the progressively expanding Middle Albian basin. It is likely that in some areas their extent oversteps all the previous ones. Aptian–Early Albian deposits yield no stratigraphically important fossils.

K2-II — MIDDLE ALBIAN (?+ EARLIEST LATE ALBIAN) (UPPER PART OF THE KRUSZWICA MEMBER)

The deposits belonging to this cycle extend far beyond the limits of the older Lower Cretaceous cycles. It results from the transgressive character and mobility of the Middle Albian basin. Its main characteristic feature is a distinct prevalence of sandstones with a considerable proportion of coarse-grained sand and gravel. Only its lower parts are in some areas intercalated with siltstones and claystones. Glauconite is abundant throughout the whole section. This cycle is repre-

sented entirely by siliciclastic shelf depositional system (Figs. 2, 4 and 5). The Middle Albian index ammonites *Hoplites dentatus* (Sowerby) and belemnites *Neohibolites oxycaudatus* Spaeth have been found in the upper part of the sequence. In the Mid-Polish Trough the K2-II/K3-I boundary is drawn between the *inflatum* and *dispar* Zones (I. Walaszczyk, 1987; R. Marcinowski, 1996) (Tab. 1). It may be correlated with a prominent well log marker over the most part of the basin (extremely high gamma-ray values) which corresponds to the onset of the great Late Cretaceous transgressive event known everywhere in Europe.

### CONCLUSIONS

The above considerations lead to the following conclusions:

1. The majority of the Lower Cretaceous deposits is represented by siliciclastic shelf depositional systems with shallow shelf sediments being predominant and occurring within all the distinguished cycles.

2. Other depositional systems i.e.: deltaic, fluvial, swampy-lacustrine, lagoonal and carbonate-clastic shelf are of minor importance.

3. The maximum high stands of sea-level occurred during the earliest Early Valanginian (Opoczki Member), early Late Valanginian, Early Hauterivian, middle (latest?) Late Hauterivian, Aptian and Middle Albian.

4. The lowest stands of sea-level were during the Early Berriasian (Skotniki and Kajetanowo Members), late Early Valanginian, latest Late Valanginian, early Late Hauterivian, Barremian and Early Albian.

5. Cycle K1 begins with the Late Berriasian transgression and is characterized by stronger differentiation of subsidence in various areas as well as the oscillatory increasing transgressive character of the basin until the Early Hauterivian, facilitating the recognition of four minor cycles.

6. Cycle K2 is related to the Aptian transgression and increasing expansion of the Middle Albian basin with more uniform subsidence.

7. The Early Berriasian deposits terminate the latest Late Jurassic sedimentary cycle — J6-VII.

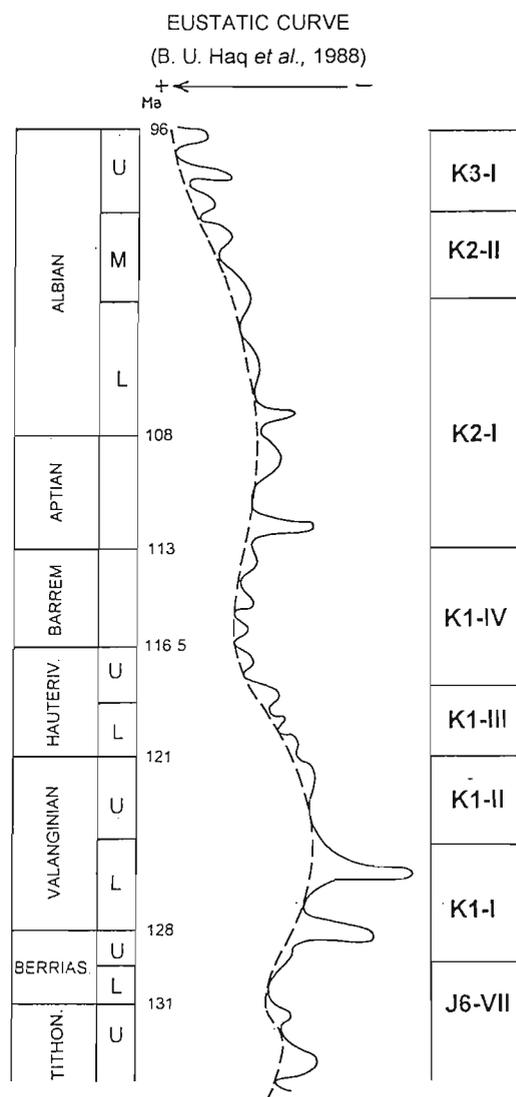


Fig. 8. Transgressive-regressive cycles in Central Poland compared with eustatic curve of B. U. Haq *et al.* (1988)

Porównanie cykli transgresywno-regresywnych Polski centralnej z krzywą eustatyczną według B. U. Haqa i in. (1988)

Translated by the Author

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## ARCHITEKTURA DEPOZYCYJNA I CYKLIČNOŚĆ SEDYMENTACJI W BASENIE DOLNOKREDOWYM BRUZDY ŚRÓDPOLSKIEJ

### Streszczenie

Analiza systemów depozycyjnych oraz cykliczności i rytmu sedymentacji w bruzdzie śródpolskiej epikontynentalnego basenu sedymentacyjnego kredy dolnej została oparta głównie na bazie danych z otworów wiertniczych (rdzenie wiertnicze, kompleksowa analiza, interpretacja i korelacja geofizyki otworowej). Spośród dużej liczby wierceń wykonanych na Niżu Polskim do analizy systemów depozycyjnych i wydzielenia cykli transgresywno-regresywnych wybrano 13 najbardziej reprezentatywnych, stosunkowo dobrze rdzeniowanych i z czytelnym zapisem geofizyki wiertniczej. Dwa wybrane otwory przedstawiono w postaci osobnych zestawień (fig. 2, 3). Wykonano korelację otworową o przebiegu mniej więcej prostopadłym do osi basenu (fig. 4). Cykliczność i sukcesja systemów depozycyjnych zobrazowane zostały syntetycznym przekrojem ideowym (fig. 5). Zasięgi niektórych cykli i paleomiąższość osadów dolnej kredy oraz rozprzestrzenienie systemów de-

pozycyjnych szelfu węglanowo-klastycznego i bagienno-jeziornego przedstawiono na mapach (fig. 1, 6, 7).

Wyróżniono sześć systemów depozycyjnych: (1) szelfu silikoklastycznego z dwoma podsystemami płytkiego i głębokiego szelfu (w obrębie tego drugiego wyróżnione zostały facje szelfu anoksycznego), (2) deltowy (prograduujących delt), (3) fluwialny, (4) bagienno-jeziorny, (5) lagunowy i (6) szelfu węglanowo-klastycznego. Ułatwiły one sprecyzowanie cykliczności sedymentacji w basenie dolnokredowym. Wyodrębnione zostały dwa cykle wyższego rzędu: K1 — zaczynający się transgresją wyższego beriasu i K2 — związany z transgresją aptu i ekspansją morza albu środkowego. W obrębie tych dwóch cykli zostało wyróżnionych sześć cykli niższego rzędu. Osady wczesnego beriasu kończą najmłodszy górnojurajski cykl sedymentacyjny — J6-VII.