Geological Quarterly, Vol. 41, No. 4, 1997, p. 475–490

PROJEKT KBN PBZ 02-03

Depositional systems and cyclicity in the intracratonic Early Jurassic basin in Poland

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(Received: 24.10.1997)

A number of depositional systems and sub-systems have been recognized within the Lower Jurassic clastic deposits of the Polish Lowlands. These are: fluvial, deltaic, swampy (with swampy-lacustrine and swampy-lagoonal sub-systems) and siliciclastic shelf system (with shallower and deeper shelf sub-systems — the former includes brackish shelf facies). On the basis of their vertical succession and lateral changes, the Lower Jurassic sediments have been subdivided into five transgressive-regressive cycles. The lowermost deposits are included into the regressive phase of the last Triassic cycle. These cycles have been compared with the eustatic curves of B. U. Haq *et al.* (1988) and A. Hallam (1988).

INTRODUCTION

The analysis of depositional systems has been conducted on a basis of boreholes situated in the Mid-Polish Trough and along its margins (Fig.1). Boreholes which provide the best geological material are shown as both correlations: Gorzów Wlkp. IG 1, Chabowo 2, Mechowo IG 1, Ustronie IG 1, Jamno IG 1 (Pomeranian line — Fig. 2) and Koło IG 4, Poddębice PIG 2, Krośniewice IG 1, Gostynin IG 1/1a, Bartoszyce IG 1 (central line — Fig. 3), and individual borehole sections (Figs. 4–7). A sedimentological profile of borehole Mechowo IG 1 has been compiled by G. Pieńkowski (1997). The above-mentioned boreholes are entirely or almost entirely cored and they have a legible wireline log record. Depositional systems and transgressive-regressive cycles are shown in the sections and correlations.

For purposes of the project the following data have been employed: (1) the author's own lithological-sedimentological studies (particularly in the central region), (2) archival materials from a few tens of boreholes located in the Polish Lowlands, (3) maps constructed by geologists of the Polish Geological Institute during many years' studies, (4) earlier lithological-biostratigraphical data (R. Dadlez, 1964, 1973; R. Dadlez, J. Dembowska, 1965; R. Dadlez, J. Kopik, 1972; Z. Deczkowski, 1977; M. Franczyk, 1983; W. Karaszewski, 1962; J. Kopik, 1964; T. Marcinkiewicz, 1964, 1971; S. Z. Różycki, 1958) and (5) earlier sedimentological investigations (G. Pieńkowski, 1983, 1988, 1997; G. Pieńkowski, P. Brański, 1988).

It must be stressed that in northwestern Poland and the Holy Cross Mts. margins there are entirely cored boreholes with comparatively abundant fossils and — in the latter area — exposures allowing detailed sedimentological analysis to be made, contrary to the central part of the Mid-Polish Trough with the greatest thickness of the Lower Jurassic deposits where well logs are supported by 2–5 m long cores taken every 50 or 100 m.

In the central region, depositional systems have been distinguished basing upon both the analysis of now available cores and detailed correlations of well logs along the Mid-Polish Trough from Pomerania to the Holy Cross Mts.

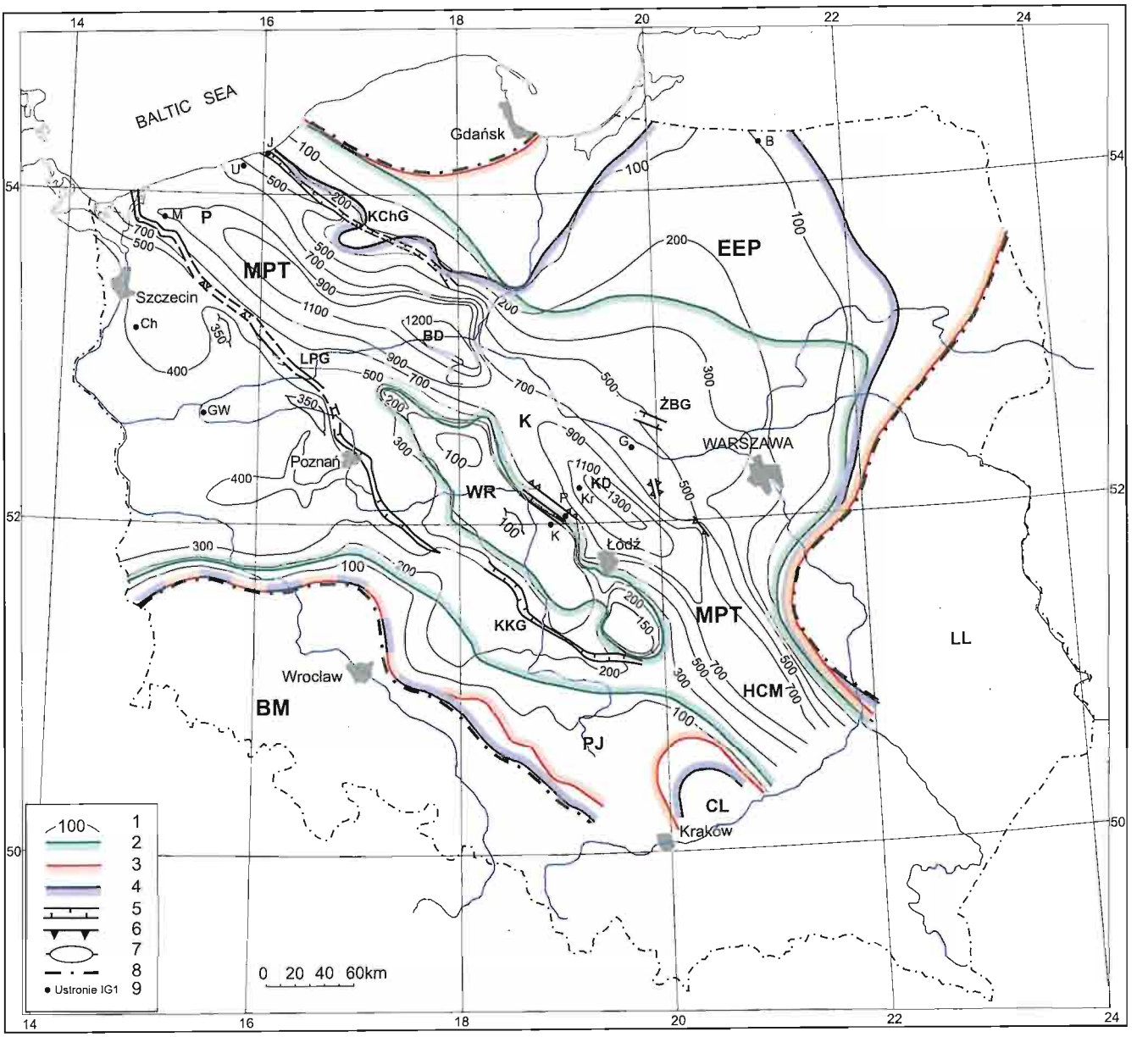


Fig. 1. The Lower Jurassic primary thickness map after Z. Deczkowski, M. Franczyk (1988) modified by A. Feldman-Olszewska

1 — restored isopachs; maximum extent of basin: 2 — Hettangian–Early Sinemurian, 3 — Late Sinemurian–Early Bathonian, 4 — Toarcian; 5 — synsedimentary grabens; 6 — synsedimentary faults; 7 — elevations; 8 — extent of the Middle Jurassic basin; 9 — interpreted borehole sections: B — Bartoszyce IG 1, Ch — Chabowo 2, GW — Gorzów Wlkp. IG 1, G — Gostynin IG 1/1a, J — Jamno IG 1, K — Koło IG 4, Kr — Krośniewice IG 1, M — Mechowo IG 1, P — Poddębice IG 1, U — Ustronie IG 1; BD — Bydgoszcz Depression, BM — Bohemian Massif, CL — Cracow Land, EEP — East European Platform, HCM — Holy Cross Mts., K — Kujawy region, KChG — Koszalin–Chojnice Graben, KD — Kutno Depression, KKG — Kaleje–Kamieńsk Graben, LL — Lublin Land, LPG — Laska–Poznań Graben, MPT — Mid-Polish Trough, P — Pomerania, PJ — Polish Jura, WR — Wielkopolska Ridge, ŻBG — Żuromin–Bieżuń Graben

Mapa paleotektoniczna jury dolnej według Z. Deczkowskiego, M. Franczyk (1988) uzupełniona przez A. Feldman-Olszewską

1 — palaeoizopachyty; maksymalne zasięgi basenów: 2 — hetangu–synemuru dolnego, 3 — synemuru górnego–pliensbachu, 4 — toarsu; 5 — rowy synsedymentacyjne; 6 — uskoki synsedymentacyjne; 7 — elewacje; 8 — zasięg basenu środkowojurajskiego; 9 — interpretowane profile otworów wiertniczych — patrz tekst angielski; BD — depresja Bydgoszczy, BM — Masyw Czeski, CL — ląd Krakowa, EEP — platforma wschodnioeuropejska, HCM — Góry Świętokrzyskie, K — Kujawy, KChG — rów Koszalina–Chojnic, KD — depresja Kutna, KKG — rów Kalej–Kamieńska, LL — ląd lubelski, LPG — rów Laski–Poznania, MPT — bruzda śródpolska, P — Pomorze, PJ — Jura Polska, WR — garb wielkopolski, ŻBG — rów Żuromina–Bieżunia

PALAEOTECTONIC AND PALAEOGEOGRAPHIC ELEMENTS OF THE EARLY JURASSIC BASIN

The main palaeotectonic element of the Early Jurassic basin is the Mid-Polish Trough existing during the whole epoch (Fig. 1). It is characterized by the complete lithological-stratigraphical sequence reaching over 1200 m in thickness in the Bydgoszcz Depression and over 1300 m in the Kutno Depression. In the Pomeranian region the trough is

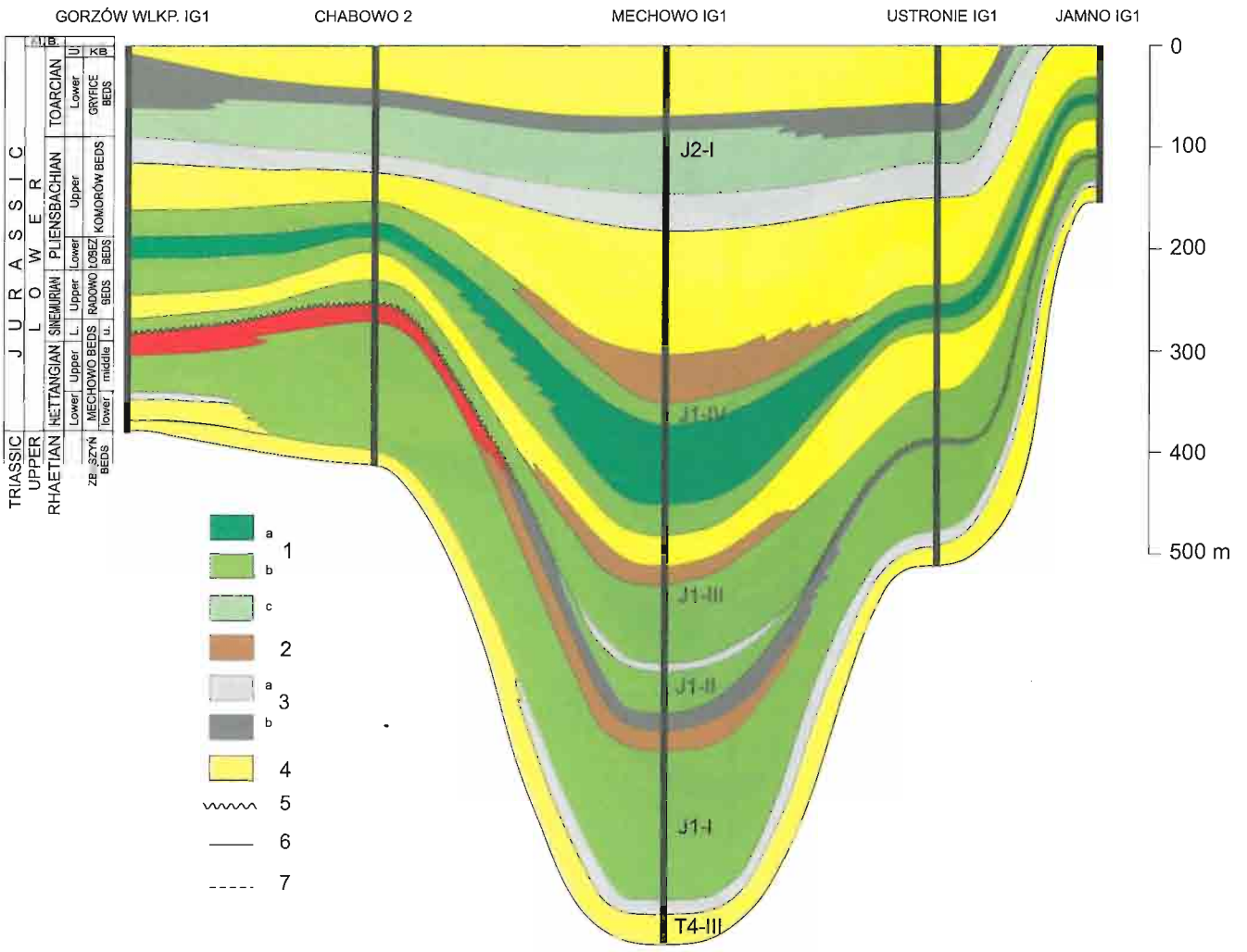


Fig. 2. Correlation of depositional systems and transgressive-regressive cycles between selected boreholes in the Lower Jurassic sequences of the Pomeranian region

1 — siliciclastic shelf system (a — deeper siliciclastic shelf sub-system, b — shallower siliciclastic shelf sub-system, c — brackish shelf facies); 2 — deltaic system; 3 — swampy system (a — swampy-lagoonal sub-system, b — swampy-lacustrine sub-system); 4 — fluvial system; 5 — erosional surfaces; 6 — boundaries between transgressive-regressive cycles; 7 — boundaries between depositional systems

Korelacja systemów depozycyjnych i cykli transgresywno-regresywnych jury dolnej w regionie pomorskim pomiędzy wybranymi otworami wiertniczymi

1 — system szelfu klastycznego (a — podsystem szelfu głębszego, b — podsystem szelfu płytszego, c — facje szelfu brakicznego); 2 — system deltowy; 3 — system bagienny (a — podsystem bagienno-lagunowy, b — podsystem bagienno-jeziorny); 4 — system fluwialny; 5 — powierzchnie erozyjne; 6 — granice cykli transgresywno-regresywnych; 7 — granice systemów depozycyjnych

bordered from the south-west by a series of the Laska–Poznań synsedimentary grabens, and from the north-east by a series of Koszalin–Chojnice synsedimentary grabens. In the central region, the trough is sharply separated in the south-west from the Wielkopolska Ridge by presumably extensional half-graben systems. In this part of the trough there is a dramatic increase in thicknesses and in the Wielkopolska Ridge area a sedimentary gap spanning presumably Hettangian and Sinemurian times and locally erosional gap comprising the Upper or whole Toarcian is recorded (R. Dadlez, M. Franczyk, 1976). North-east of the central region, the Mid-Polish Trough passes more gradually into the East European Platform. In this part of the basin, at the contact between the above-mentioned tectonic units, there are also several minor synsedimentary grabens and horsts (Żuromin–Bieżuń Graben, Płońsk zone, Nasielsk–Dębe Graben, Kompina–Różyce zone) not linked with one another. Apart from the listed tectonic elements, the Kaleje–Kamieńsk Graben bordering the Wielkopolska Ridge from the south-west must be mentioned.

The Early Jurassic basin was surrounded by land areas subjected to denudation: marginal parts of the East European Craton from the north-east, Bohemian Massif from the south-west and Cracow Land from the south. It is also likely that, at least during the Hettangian, the Cracow and Lublin areas were joined together.

Salt tectonics considerably influenced the sedimentation and evolution of the Early Jurassic basin. It resulted in the formation of locally elevated zones and related to them down-

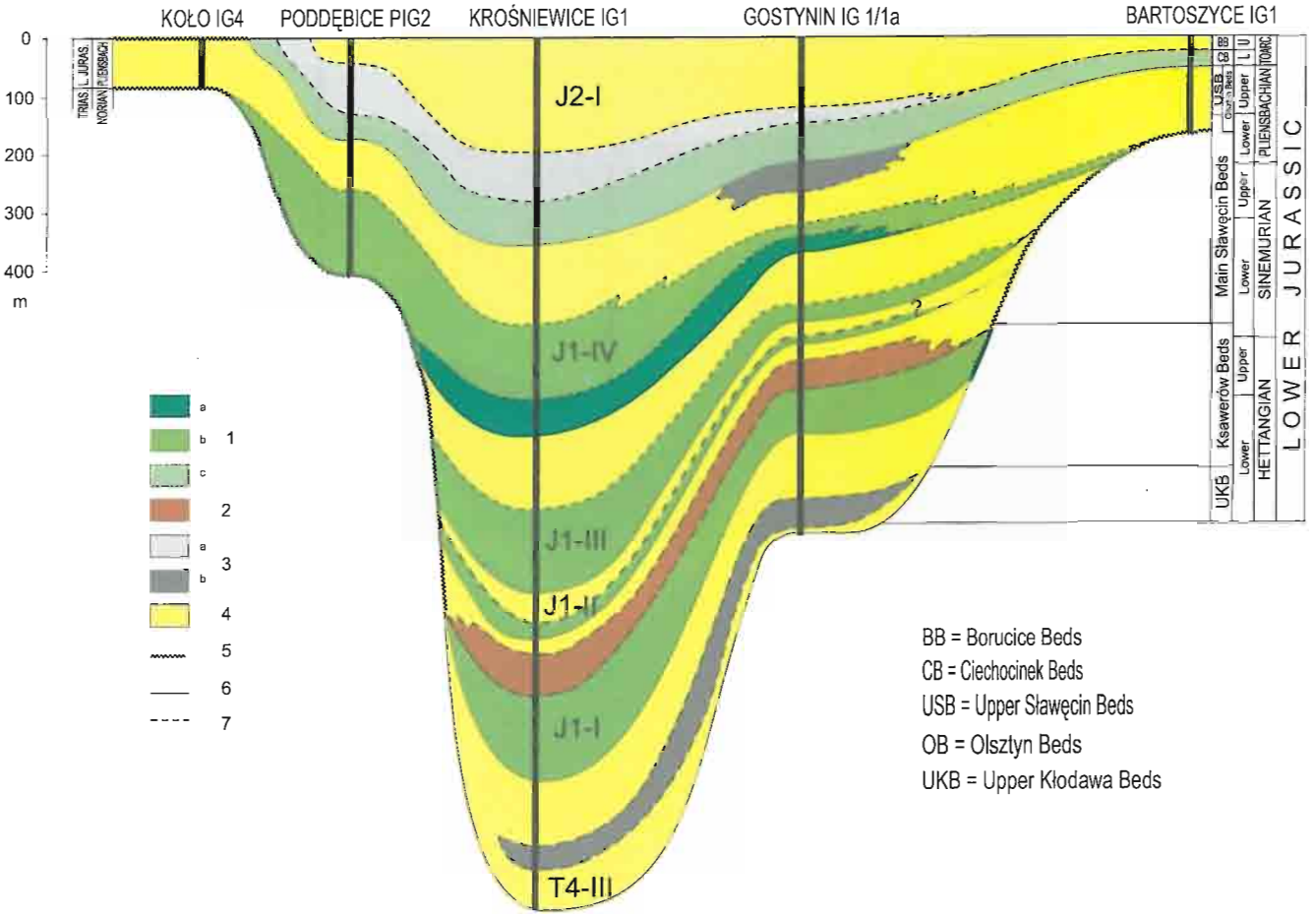


Fig. 3. Correlation of depositional systems and transgressive-regressive cycles between selected boreholes in the Lower Jurassic sequences of Central Poland

1 — siliciclastic shelf system (a — deeper siliciclastic shelf sub-system, b — shallower siliciclastic shelf sub-system, c — brackish shelf facies); 2 — deltaic system; 3 — swampy system (a — swampy-lagoonal sub-system, b — swampy-lacustrine sub-system); 4 — fluvial system; 5 — erosional surfaces; 6 — boundaries between transgressive-regressive cycles; 7 — boundaries between depositional systems

Korelacja systemów depozycyjnych i cykli transgresywno-regresywnych dolnej jury centralnej Polski między wybranymi otworami wiertniczymi

1 — system szelfu klastycznego (a — podsystem szelfu głębszego, b — podsystem szelfu płytszego, c — facje szelfu brakicznego); 2 — system deltowy; 3 — system bagienny (a — podsystem bagienno-lagunowy, b — podsystem bagienno-jeziorny); 4 — system fluwialny; 5 — powierzchnie erozyjne; 6 — granice cykli transgresywno-regresywnych; 7 — granice systemów depozycyjnych

warped areas (R. Dadlez, 1979; R. Dadlez, S. Marek, 1977). Such zones were located south of grabens and faults which bordered the Mid-Polish Trough. These are elevations situated south of the Laska–Poznań Graben as well as in the Wielkopolska Ridge area (Z. Deczkowski, M. Franczyk, 1988). In the central part of the Mid-Polish Trough (Kujawy region), synsedimentary growth of salt pillows also took place.

DEPOSITIONAL SYSTEMS

The following depositional systems have been recognized within the Lower Jurassic sequence in the Polish Lowlands:

(1) fluvial system:
— braided river sub-system,
— meandering river sub-system;
(2) swampy system:
— swampy-lacustrine sub-system,
— swampy-lagoonal sub-system;
(3) deltaic system;
(4) siliciclastic shelf system:
— shallower siliciclastic shelf sub-system,
— brackish shelf facies,
— deeper siliciclastic shelf sub-system.

Spatial relationships between the sub-systems and systems within each cycle are shown in Table 1 and Figure 8.

Table 1

Subdivision of the Lower Jurassic and sedimentary cyclicity in Polish Lowlands (stratigraphy after R. Dadlez, J. Kopik, 1972; S. Z. Różycki, 1958 and W. Karaszewski, 1962)

<table>
<tr><th rowspan="2">CYCLES</th><th rowspan="2">DEPOSITIONAL SYSTEM</th><th colspan="2">CHRONOSTRATI-GRAPHY</th><th colspan="3">LITHOSTRATIGRAPHY</th></tr>
<tr><th>Stage</th><th>Sub-stage</th><th>Western Poland</th><th>Kujavian Swell</th><th>Margins of the Holy Cross Mts.</th></tr>
<tr><td rowspan="5">J2-I</td><td colspan="3">fluvial</td><td rowspan="2">Toarcian</td><td>Upper</td><td>Kamień Beds</td><td>Borucice Beds</td><td>Borucice Beds</td></tr>
<tr><td>lagoonal</td><td colspan="2">fluvial</td><td>Lower</td><td>Gryfice Beds</td><td>Ciechocinek Beds</td><td>Ciechocinek Formation</td></tr>
<tr><td colspan="4">brackish shelf facies</td><td rowspan="4">Pliensba-chian</td><td rowspan="3">Upper</td><td rowspan="3">Komorów Beds</td><td rowspan="3">Upper Sławęcin Beds</td><td rowspan="3">Drzewica Formation</td></tr>
<tr><td>lagoonal</td><td>fluvial</td><td>swampy-lacustrine</td></tr>
<tr><td rowspan="4">J1-IV</td><td>fluvial</td><td colspan="2" rowspan="3">fluvial</td></tr>
<tr><td>deltaic</td></tr>
<tr><td>shallower siliciclastic shelf</td><td rowspan="2">Lower</td><td rowspan="2">Łobez Beds</td><td rowspan="5">Main Sławęcin Beds</td><td rowspan="2">Gielniów Formation</td></tr>
<tr><td>deeper siliciclastic shelf</td><td>shallower siliciclastic shelf</td></tr>
<tr><td colspan="3">shallower siliciclastic shelf</td><td rowspan="4">Sinemu-rian</td><td rowspan="2">Upper</td><td rowspan="2">Radowo Beds</td><td rowspan="2">Koszorów + Ostrowiec Formations</td></tr>
<tr><td rowspan="2">J1-III</td><td colspan="3">fluvial</td></tr>
<tr><td>deltaic</td><td colspan="2">fluvial</td><td rowspan="3">Lower</td><td rowspan="3">Upper Mechowo Beds</td></tr>
<tr><td colspan="3">shallower siliciclastic shelf</td><td rowspan="2">Ore-Bearing Formation</td></tr>
<tr><td>J1-II</td><td>fluvial</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>shallower siliciclastic shelf</td></tr>
<tr><td rowspan="5">J1-I</td><td>swampy-lacustrine</td><td colspan="2" rowspan="2">fluvial</td><td rowspan="3">Ksawerów Beds</td></tr>
<tr><td>deltaic</td><td rowspan="2">Middle Mechowo Beds</td></tr>
<tr><td colspan="3">shallower siliciclastic shelf</td><td rowspan="3">Hettan-gian</td><td rowspan="2">Upper</td><td>Skłoby Formation</td></tr>
<tr><td>shallower siliciclastic shelf</td><td>fluvial</td><td rowspan="3">swampy-lacustrine</td><td rowspan="2">Lower Mechowo Beds</td><td rowspan="2">Zagaje Formation</td></tr>
<tr><td rowspan="2">swampy-lagoonal</td><td rowspan="2">swampy-lacustrine</td><td rowspan="2">Lower</td><td rowspan="2">Upper Kłodawa Beds</td></tr>
<tr><td>T4-III</td><td>fluvial</td><td>fluvial</td></tr>
</table>

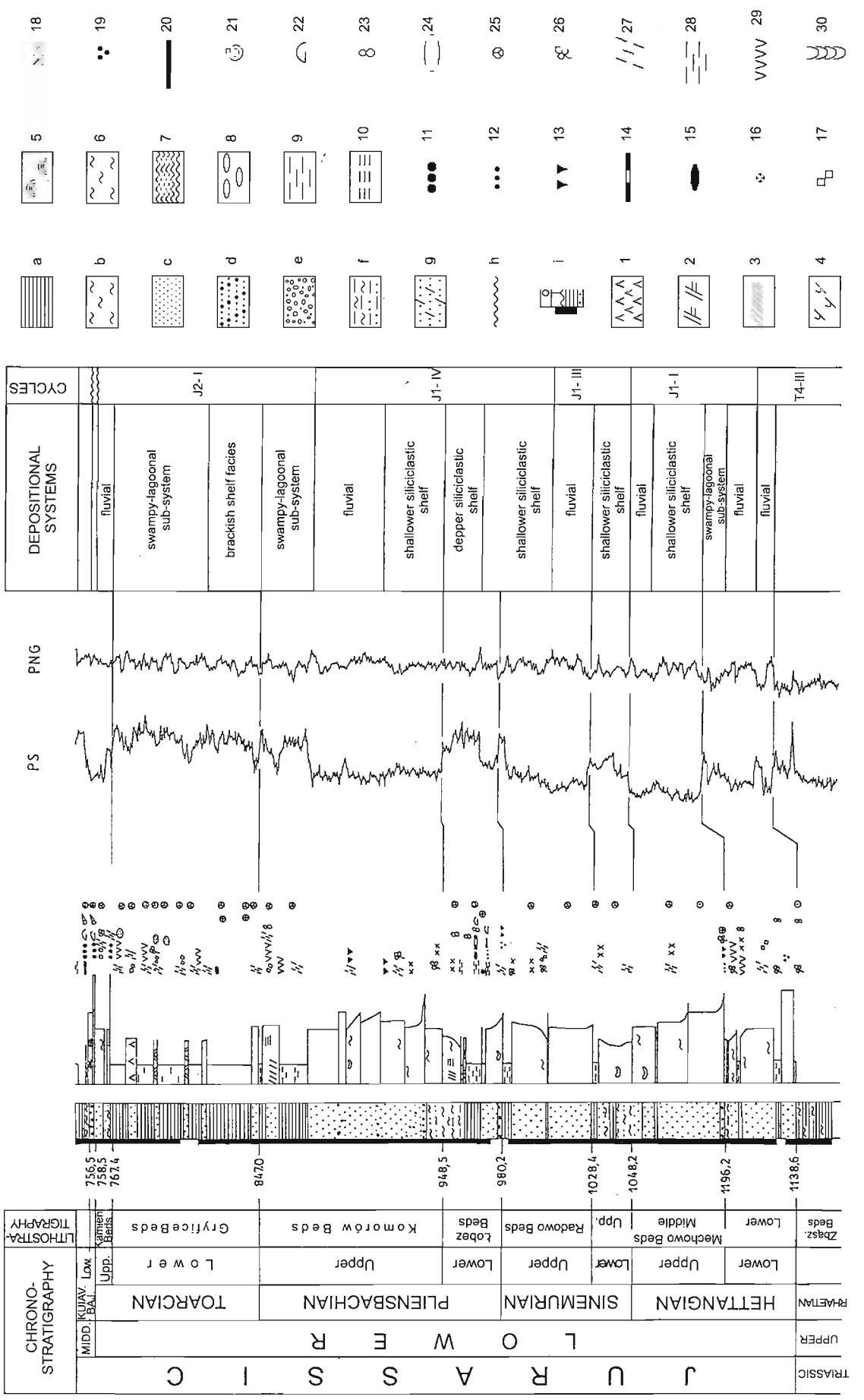
FLUVIAL SYSTEM

Braided river sub-system — packages of sandstones, gravels and quartz conglomerates, up to twenty metres thick, with large-scale cross bedding. These deposits have been recognized in the marginal parts of the basin (the Polish Jura, Holy Cross Mts. margin — lower part of the Zagaje Formation) (G. Pieńkowski, 1983, 1988) where they overlie an erosional surface marking a gap which comprises the uppermost Rhaetian and perhaps even the lowermost Liassic (G. Pieńkowski, 1997)

Meandering river sub-system — light grey, fine-, medium- and vari-grained sandstones. They are characterized by the presence of either sandy members only (channel deposits) or normal cycles (channel deposits overlain by alluvial plain). The sandstones show trough bedding, planar bedding or they are massive with rare clayey flaser laminae enriched in coalified plant detritus. They are also characterized by the low grade of textural maturity, the presence of erosional surfaces covered by gravel horizons and occurrence of abundant coalified plant detritus as well as large plant fragments. Rhizoids, forming ancient soil horizons have also been found. Meandering river deposits represent regressive phases of sedimentary cycles. They occur below the first Early Jurassic transgression over the whole Mid-Polish Trough and in the marginal zones (East European Platform — Olsztyn Beds and Borucice Beds), and they terminate transgressive-regressive cycles J1-III, J1-IV and J2-I (in Pomerania they comprise the upper part of the Radowo Beds, Komorów Beds and Kamień Beds; in the central area — the middle part of the Main Sławęcin Beds, the upper part of the Upper Sławęcin Beds and the Borucice Beds; in the Holy Cross Mts. margin — the lowermost part of the Ostrowiec Formation, part of the Drzewica Formation and the Borucice Formation). In the Polish Jura, meandering river deposits constitute the Blanowice and Łysiec Beds.

SWAMPY SYSTEM

Swampy-lacustrine sub-system — dark grey and grey-olive muddy deposits with frequent lenticular or wavy lamination. They are also rich in coalified plants, rhizoid horizons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CYCLES
DEPOSITIONAL SYSTEMS
fluvial
swampy-lagoonal sub-system
brackish shelf facies
swampy-lagoonal sub-system
fluvial
shallower siliciclastic shelf
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shallower siliciclastic shelf
swampy-lagoonal sub-system
fluvial
fluvial
J2- I
J1- IV
J1- III
J1- I
T4-III
PS
PNG
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758.5
767.4
847.0
948.5
980.2
1028.4
1048.2
1196.2
1138.6
LITHOSTRATIGRAPHY
Kamien Beds
Gryfice Beds
Komorów Beds
Lobez Beds
Radowo Beds
Upp.
Mechowo Beds
Middle
Lower
Zbąsz. Beds
CHRONO-STRATIGRAPHY
Upp.
Low.
Lower
Upper
Lower
Upper
Lower
Upper
Lower
Upper
Lower
Lower
TOARCIAN
PLIENSBACHIAN
SINEMURIAN
HETTANGIAN
KUJAV. BAJ.
MIDD.
L O W E R
UPPER
J U R A S S I C
TRIASSIC
RHAETIAN

and coal intercalations. Rare fresh-water fauna and ichnofauna have been recorded. As a thick complex, these sediments occur only in the southeastern part of the Mid-Polish Trough forming the Zagaje Formation (120 m in thickness) and in the Polish Jura where they compose a part of the Coal Beds (G. Pieńkowski, 1988). In Central and Western Poland, swampy-lacustrine deposits are present only in the Hettangian (upper part of the Upper Kłodawa Beds, lower part of the Ksawerów Beds, upper part of the Upper Mechowo Beds).

Swampy-lagoonal sub-system — dark grey muddy deposits, up to 30 m thick, rich in plant remains, rhizoids, desiccation-syneresis cracks and coal horizons separating deposits with brackish bivalves, agglutinated foraminifers, feeding traces, sideritic and pyritic concretions. They usually show no sedimentary structures. Lenticular lamination can sometimes be observed. These sediments form the ore-bearing horizons in the Holy Cross Mts. margin, mark the onset of the 1st and 5th transgression in Pomerania (upper part of the Lower Mechowo Beds and uppermost part of the Komorów Beds in borehole Mechowo IG 1) and the beginning of the regressive phase of cycle J2-I (upper part of the Ciechocinek Beds in the central region and upper part of the Gryfice Beds in the Pomeranian region of the Mid-Polish Trough).

DELTAIC SYSTEM

This system is represented by sandy and muddy deposits arranged in coarsening upward cycles of clastic sequences succeeded in the upper part by fining upward cycles reflecting the transition from fine-grained (muddy) prodelta deposits through coarser-grained sandy delta front sediments, again into finer-grained muddy delta plain sediments. Muscovite, abundant coalified plant detritus, kaolinite, sideritic concretions and pyrite are present here. It seems that Early Jurassic deltas were of river-dominant character and they were prograding into a shallow-marine basin of low salinity or into bays and lagoons.

Deltaic deposits have been recognized within the Skłoby Formation, in sandstones between ore-bearing horizons of the Ore-Bearing Formation and within the Ostrowiec and Drzewica Formations of the Holy Cross Mts. margin (G. Pieńkowski, 1997). They also occur within the "Łysiec Beds" of the Polish Jura (G. Pieńkowski, 1988) as well as in Pomerania within the Lower and Middle Mechowo, Radowo and Komorów Beds (G. Pieńkowski, 1997) overlying shallow siliciclastic shelf deposits. It is probable that the lower part of the Main Sławęcin Beds resting in the central region upon shallow-marine deposits of the Ksawerów Beds may also represent deltaic environment. Deltaic deposits are usually overlain by fluvial sediments, sometimes (e.g. in the Mechowo Beds) by shallow siliciclastic shelf deposits.

SILICICLASTIC SHELF SYSTEM

Shallower siliciclastic shelf sub-system — sandy or sandy-heterolithic complexes, several tens of metres thick. The sandstones are most frequently fine- to medium-grained of high maturity with dolomitic and calcareous intercalations. They show tabular, hummocky or low-angle cross bedding and planar bedding. Heteroliths are wavy, flaser and lenticular bedded. One of the most characteristic features here is also the presence of trace fossils, among others *Diplocraterion* ichnosp. Shallow shelf deposits occasionally contain pebbles, mud clasts, Fe-oolites, feeding structures, resting traces of bivalves and in the Pomeranian region also scarce agglutinated foraminifers and brackish bivalves (J. Kopik, 1964; W. Karaszewski, 1962; G. Pieńkowski, 1983).

These sediments were deposited in a shallow, vast basin, frequently of lowered salinity, within the upper offshore (heteroliths), shoreface and foreshore (barriers and beaches — sandstones) zones above storm wave-base. Shallow shelf deposits mark the onset of transgressive-regressive cycles J1-I, J1-II and J1-III, and appear within the highstand systems tract of cycle J1-IV. In the Pomeranian region they occur within the Mechowo Beds, lower part of the Radowo Beds and the upper part of the Łobez Beds; in the central region they compose the middle and upper part of the Ksawerów Beds, lower and middle part of the Main Sławęcin Beds and lower part of the Upper Sławęcin Beds. In the Holy Cross region they have been recognized within the Skłoby Forma-

Fig. 4. Lower Jurassic depositional systems and cyclicity in the Gorzów Wlkp. IG 1 borehole section

L i t h o l o g y : a — shales, claystones, b — siltstones, c — very fine-grained and fine-grained sandstones, d — medium-, coarse-grained sandstones, e — gravel, conglomerates, f — argillaceous siltstones and sandstones, g — dolomitic sandstones, h — erosional surfaces, i — cores; s e d i m e n t a r y s t r u c t u r e s : 1 — flaser bedding, 2 — low-angle cross bedding, 3 — tabular cross bedding, 4 — trough cross bedding, 5 — hummocky cross stratification, 6 — clay laminae, 7 — wavy bedding, 8 — lenticular bedding, 9 — lenticular lamination, 10 — planar bedding, 11 — pebbles, 12 — quartz gravels, 13 — clay clasts, 14 — sideritic horizons, 15 — sideritic concretions, 16 — ferruginous oolites, 17 — mica, 18 — pyrite, 19 — kaolinite, 20 — coal, 21 — ammonites, 22 — bivalves, 23 — foraminifera, 24 — estheria, 25 — megaspores, 26 — flora remains, 27 — coalified flora detritus, 28 — pyritized flora detritus, 29 — rhizoids, 30 — *Diplocraterion* ichnosp.

Systemy depozycyjne i cykliczność w jurze dolnej w otworze Gorzów Wlkp. IG 1

L i t o l o g i a : a — łupki ilaste i iłowce, b — mułowce, c — piaskowce bardzo drobno- i drobnoziarniste, d — piaskowce średnio- i gruboziarniste, e — żwiry i zlepieńce, f — piaskowce i mułowce ilaste, g — piaskowce dolomityczne, h — powierzchnie erozyjne, i — zakres rdzeniowania; s t r u k t u r y s e d y m e n t a c y j n e : 1 — warstwowanie smużyste, 2 — warstwowanie przekątne niskokątne, 3 — warstwowanie przekątne tabularne, 4 — warstwowanie przekątne rynnowe, 5 — warstwowanie kopułowe, 6 — pojedyncze przesmużenia ilaste, 7 — warstwowanie faliste, 8 — warstwowanie soczewkowe, 9 — laminacja soczewkowa, 10 — warstwowanie poziome, 11 — otoczaki, 12 — żwirek kwarcowy, 13 — klasty ilaste, 14 — poziomy syderytyczne, 15 — konkrecje syderytyczne, 16 — oolity żelaziste, 17 — muskowit, 18 — piryt, 19 — kaolinit, 20 — węgiel, 21 — amonity, 22 — małże, 23 — otwornice, 24 — esterie, 25 — megaspory, 26 — fragmenty flory, 27 — uwęglona sieczka roślinna, 28 — spirytyzowana sieczka roślinna, 29 — rizoidy, 30 — *Diplocraterion* ichnosp.

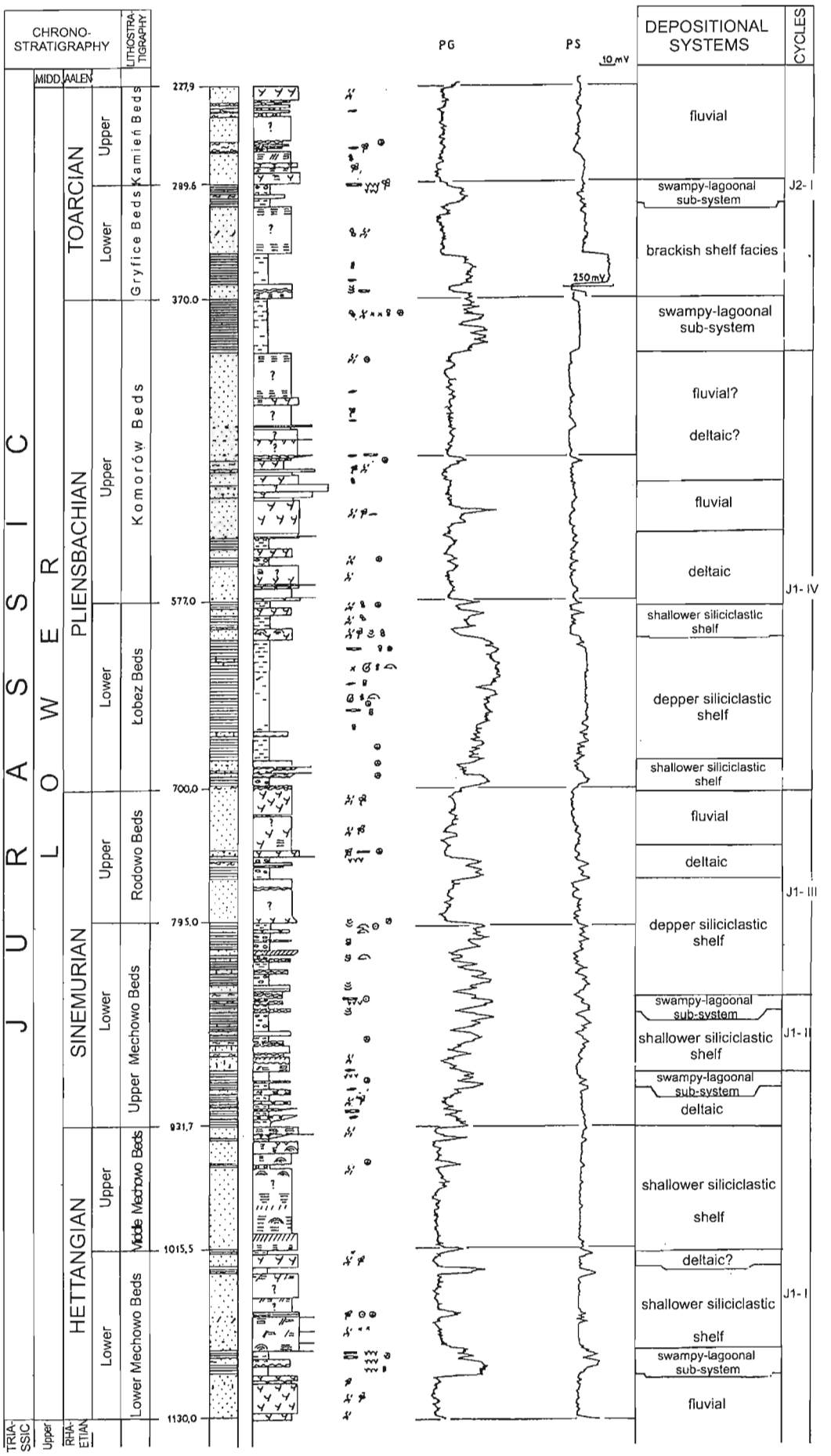

Fig. 5. Lower Jurassic depositional systems and cyclicity in the Mechowo IG 1 borehole section; sedimentological section after G. Pieńkowski (1997)
For explanations see Fig. 4

Systemy depozycyjne i cykliczność w jurze dolnej w otworze Mechowo IG 1; profil sedymentologiczny według G. Pieńkowskiego (1997)
Objaśnienia na fig. 4

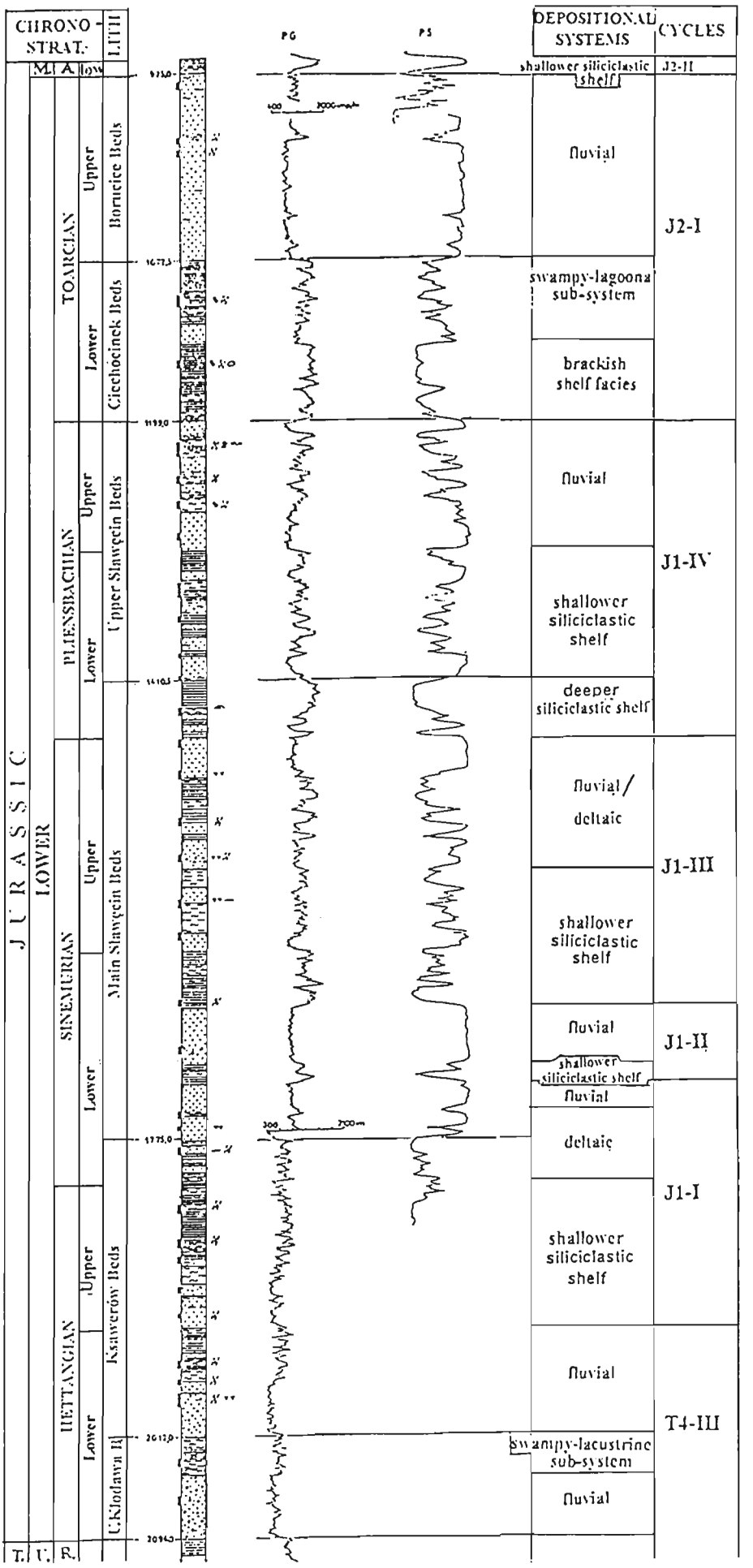

Fig. 6. Lower Jurassic depositional systems and cyclicity in the Krośniewice IG 1 borehole section
For explanations see Fig. 4

Systemy depozycyjne i cykliczność w jurze dolnej w otworze Krośniewice IG 1
Objaśnienia na fig. 4

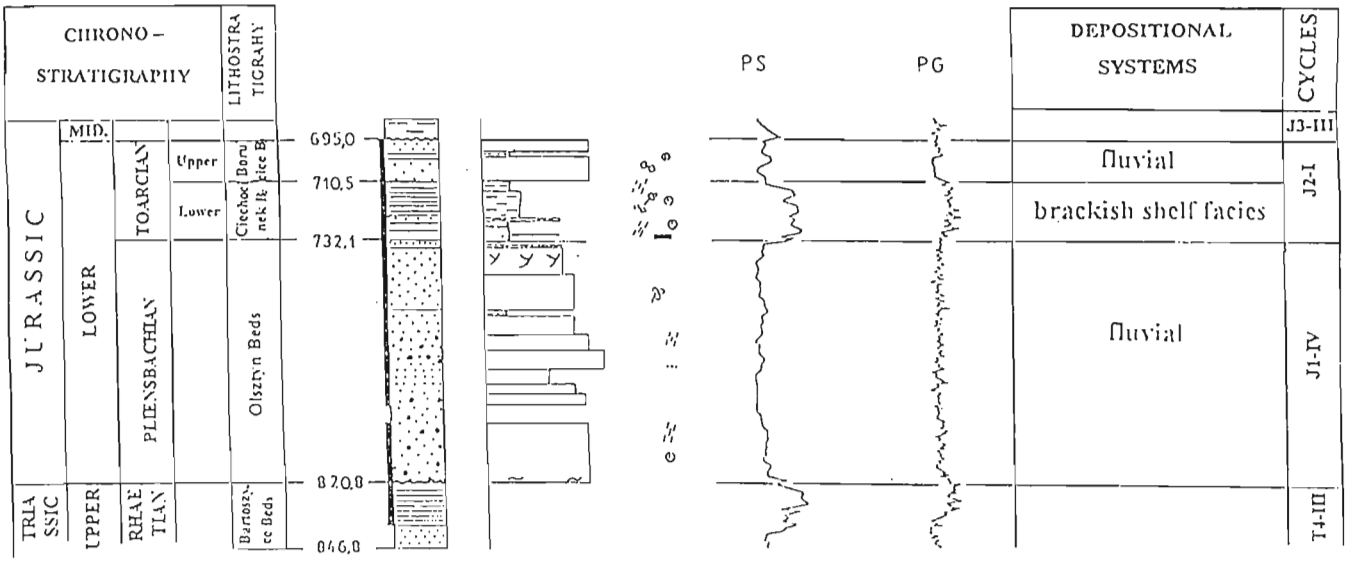

Fig. 7. Lower Jurassic depositional systems and cyclicity in the Bartoszyce IG 1 borehole section
For explanations see Fig. 4

Systemy depozycyjne i cykliczność w jurze dolnej w otworze Bartoszyce IG 1
Objaśnienia na fig. 4

tion, lower part of the Ostrowiec Formation and lower part of the Drzewica Formation. Barrier and beach deposits are also represented between the ore-bearing horizons of the Ore-Bearing Formation (G. Pieńkowski, 1983, 1997). Shallow shelf heteroliths with marine bivalves have also been recorded from the Sub-Coal Beds in the Polish Jura (G. Pieńkowski, 1988).

Brackish shelf facies — grey-green muddy and heterolithic deposits. They are parallelly or lenticularly laminated, with lenticular bedding. Claystones are locally non-laminated. They are occasionally interbedded with sandy layers showing features of tempestites. Coalified plant detritus, muscovite, siderites, estheria and agglutinated foraminifers have been recorded from these deposits. In the Polish Jura, *Diplocraterion* ichnosp., a trace fossil characteristic of the middle shoreface zone, has been found. These deposits, representing the lower part of the Gryfice Beds and Ciechocinek Beds (so-called Green Series), are common over the whole area of the Polish Lowlands reaching up to 50–60 m in thickness. Only in northeastern Poland they are more sandy. Muddy sediments are locally light grey and do not exceed 40 m in thickness there (R. Dadlez, 1964, 1973). Clastic brackish basin deposits compose the lower, transgressive part of the Early Jurassic transgressive-regressive cycle J2-I.

Deeper siliciclastic shelf sub-system — 20–60 m thick complex of dark grey mudstones with either lenticular bedding and lamination or completely structureless. They contain marine fauna of ammonites (in the Łobez Beds only), agglutinated and calcareous foraminifers, bivalves and trace fossils. These deposits appear in the Early Jurassic only within the transgressive systems tract of cycle J1-IV, composing the Łobez Beds in Pomerania and, most likely, the uppermost part of the Main Sławęcin Beds in the central region, as well as the upper part (muddy) of the Gielniów Formation in the Holy Cross Mts. margin

TRANSGRESSIVE-REGRESSIVE CYCLES

Five 3rd-order transgressive-regressive cycles (1–10 Ma long each) can be recognized in the Lower Jurassic of the Polish Lowlands (Tab. 1, Fig. 8).

T4-III. The Lower Jurassic sequence begins with fluvial and swampy deposits representing the regressive phase of the last Triassic cycle. In the lithostratigraphical subdivision in Poland they are correlated with the lower part of the Lower Mechowo Beds of Pomerania (Fig. 5), Upper Kłodawa Beds and the lower part of the Ksawerów Beds in the central region (Fig. 6) and also Zagaje Formation of the Holy Cross Mts. margin (Tab. 1). Basing upon the megaspore *Nathorstisporites hopliticus* Jung (Mechowo IG 1 — T. Marcinkiewicz, 1964; Gorzów Wlkp. IG 1 — T. Marcinkiewicz, 1971; Konary IG 1 — T. Marcinkiewicz, unpublished) and the miospores *Aratrisporites minimus* Schulz (Opoczno PIG 2 — A. Fijałkowska, unpublished), *Pinuspollenites minimus* (Couper) (Ostałów PIG 2 — A. Fijałkowska, unpublished), *Lycostrobus scotii* Nathorst (Gorzów Wlkp. IG 1) they may

be assented to be Hettangian in age. Because the overlying marine deposits are correlated with a transgression which took place in the *planorbis* Zone, so the described sediments must correspond to the lowest zone comprising the Lower Hettangian. It is possible that, moving towards the Holy Cross Mts. margin, the studied deposits comprise larger and larger part of the *planorbis* Zone and perhaps even the lower part of the *liasicus* Zone, since it seems that the first Liassic transgression was diachronous in the Polish Lowlands. The upper part of cycle T4-III corresponds to the shelf margin wedge systems tract (SMW) in the eustatic curve of B. U. Haq *et al.* (1988) (Fig. 9).

J1-I. This cycle comprises the whole remaining part of the Hettangian and earliest Sinemurian. Its transgressive phase is represented by shallower shelf siliciclastic deposits overlain by deltaic sediments followed by fluvial (e.g. borehole Krośniewice IG 1 — Fig. 6; Gorzów Wlkp. IG 1 — Fig. 4) or swampy ones (Mechowo IG 1 — Fig. 5). This cycle corresponds to the upper part of the Lower Mechowo Beds, Middle Mechowo Beds, and the lower part of the Upper Mechowo Beds in Pomerania, Ksawerów Beds and the lowest part of the Main Sławęcin Beds in the central region, most of the Liwiec Beds in the eastern Warsaw Trough, the Skłoby Formation and the lower part of the Ore-Bearing Formation in the Holy Cross Mts. margin (Tab. 1).

The whole cycle is dated by the megaspores *Nathorstisporites hopliticus* Jung (Mechowo IG 1 — T. Marcinkiewicz, 1964; Gorzów Wlkp. IG 1, Wielichowo, Koszalin IG 1, Suliszewo 1 — T. Marcinkiewicz, 1971; Warsaw Trough — M. Franczyk, 1983; Holy Cross Mts. margin — W. Karaszewski, 1962, T. Marcinkiewicz, unpublished; Polish Jura — T. Marcinkiewicz, unpublished, Z. Deczkowski, 1977) and the miospores *Lycostrobus scotii* Nathorst (Holy Cross Mts. margin — W. Karaszewski, 1962) and *Aratrisporites minimus* Schulz (Raducz IG 1 — M. Franczyk, 1983; Ostałów PIG 2 — A. Fijałkowska, unpublished).

G. Pieńkowski (1991, 1997) correlates the transgression of cycle J1-I with the worldwide transgression of the *planorbis* Zone suggesting that this transgression was synchronous over the whole Polish Lowlands area. Analysing the correlations of wireline logs in many boreholes located along the Mid-Polish Trough (Mechowo IG 1, Piaski IG 1, Resko 1, Czaplinek IG 1, Złotów 2, Piła IG 1, Zabartowo 1, Bydgoszcz IG 1, Konary IG 1, Byczyna 1, Brześć Kujawski IG 1, Krośniewice IG 1, Zgierz IG 1, Jeżów IG 1, Rawa Mazowiecka 1, Studzianna IG 2, Opoczno PIG 2 and Ostałów PIG 2) the author has come to a conclusion that this transgression is diachronous and its beginning in the Holy Cross Mts. margin (bottom of the Skłoby Formation) should be correlated with the lowermost part of the Middle Mechowo Beds in Pomerania.

The J1-I cycle corresponds well with both B. U. Haq *et al.* (1988) and A. Hallam (1988) eustatic curves (Fig. 9).

J1-II. This cycle comprises the Early Sinemurian. Its transgressive phase is represented by shallower siliciclastic shelf deposits whereas the regressive one is pronounced by swampy-lagoonal (Mechowo IG 1 — Fig. 5) or deltaic and fluvial (Krośniewice IG 1 — Fig. 6) sediments.

This cycle comprises the middle and upper part of the Upper Mechowo Beds in Pomerania, lower part of the Main Sławęcin Beds in the central region, and the Ore-Bearing Formation together with the lowermost part of the Ostrowiec Formation in the Holy Cross Mts. margin (Tab. 1). G. Pieńkowski (1991, 1997) correlates this part of the Upper Mechowo Beds with the Ostrowiec Formation. The present author, however, basing upon the above-mentioned correlation along the Mid-Polish Trough is convinced that the Ore-Bearing Formation is equivalent to the Upper Mechowo Beds. This opinion is consistent with R. Dadlez's views (1973, 1978).

Basing upon the analysis of sections in the Szczecin–Piotrków area, it seems that the sea did not transgressed this region and was limited only to the Mid-Polish Trough. The transgressive phase of this cycle is dated in its lower part by the megaspore *Nathorstisporites hopliticus* Jung (Mechowo IG 1 — T. Marcinkiewicz, 1964; Gorzów Wlkp. IG 1 — T. Marcinkiewicz, 1971), thus it commenced during the Early Sinemurian or earlier.

Cycle J1-II corresponds with both B. U. Haq *et al.* (1988) and A. Hallam (1988) eustatic curves (Fig. 9).

J1-III. This cycle represents Late Sinemurian times. Its transgressive phase consists of shallower siliciclastic shelf deposits whereas the regressive one is pronounced by deltaic and fluvial sediments (correlations — Figs. 2 and 3). This cycle comprises the upper part of the Upper Mechowo and Radowo Beds (Mechowo IG 1 — Fig. 5), most part of the Main Sławęcin Beds up to the top clayey series in the central region (Krośniewice IG 1 — Fig. 6) and the Ostrowiec Formation (Ostrowiec and Koszorów Formations *sensu* W. Karaszewski, 1962).

This sedimentary cycle has poor biostratigraphical documentation. In the upper part of the Upper Mechowo Beds of borehole Gorzów Wlkp. IG 1, the megaspore *Nathorstisporites hopliticus* Jung (T. Marcinkiewicz, 1971) has been found. Radowo Beds of boreholes Mechowo IG 1 and Gorzów Wlkp. IG 1 have yielded *Maexisporites planatus* (Marcinkiewicz) Marcinkiewicz (T. Marcinkiewicz, 1964, 1971).

Cycle J1-III corresponds with both B. U. Haq *et al.* (1988) and A. Hallam (1988) eustatic curves (Fig. 9).

J1-IV. This cycle represents the whole Pliensbachian. It covers, for the first time, the entire area of the Polish Lowlands. It occurs in the Mid-Polish Trough, Szczecin Trough, Gorzów Block, Wielkopolska Ridge and northeastern Poland. In the areas of sedimentary continuity (Mid-Polish Trough and Szczecin–Gorzów region), the transgressive phase of this cycle is represented by mudstones of deeper siliciclastic shelf. Slow falling of sea-level during this cycle resulted in that the deeper shelf sediments are overlain by claystone-sandstone series of shallower shelf and followed by deltaic and fluvial deposits terminating this cycle. In the areas where the Early Jurassic deposition was initiated by this cycle, fluvial sediments occur.

The transgressive phase is represented by the Łobez Beds in Pomerania, the uppermost part of the Main Sławęcin Beds in the central region (claystone complex at their top) and the Gielniów Formation in the northern margin of the Holy Cross

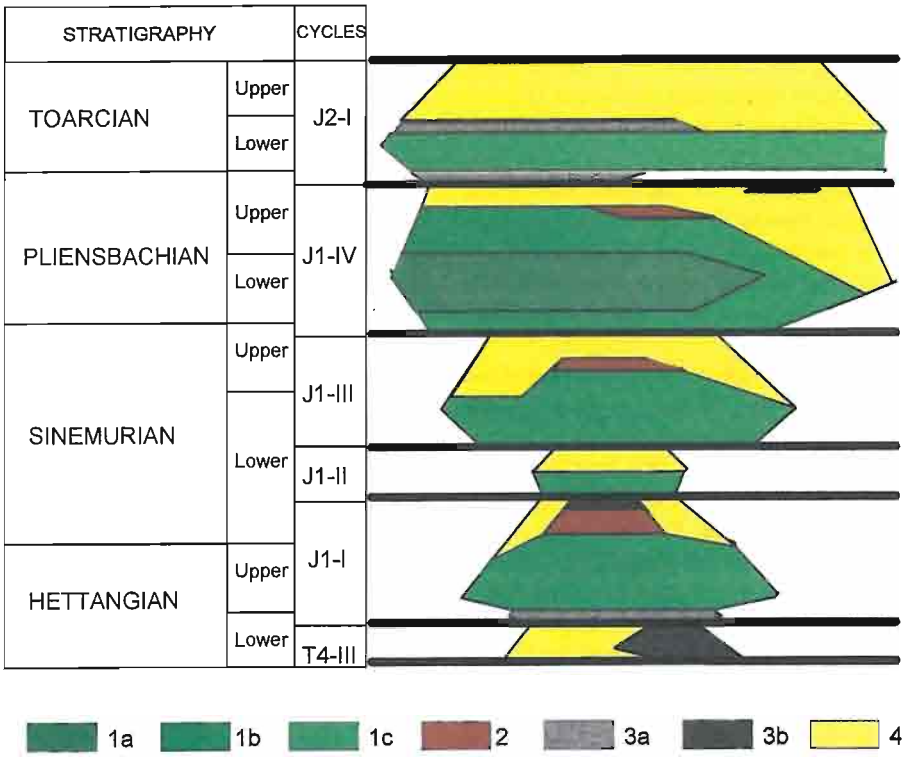

Fig. 8. Schematic diagram showing the succession of the Lower Jurassic depositional systems in the Polish Lowlands
1 — siliciclastic shelf system (a — deeper siliciclastic shelf sub-system, b — shallower siliciclastic shelf sub-system, c — brackish shelf facies); 2 — deltaic system; 3 — swampy system (a — swampy-lagoonal sub-system, b — swampy-lacustrine sub-system); 4 — fluvial system

Schematyczny przekrój obrazujący następstwo systemów depozycyjnych w jurze dolnej na Niżu Polskim
1 — system szelfu klastycznego (a — podsystem szelfu głębszego, b — podsystem szelfu płytszego, c — facje szelfu brakicznego); 2 — system deltowy; 3 — system bagienny (a — podsystem bagienno-lagunowy, b — podsystem bagienno-jeziorny); 4 — system fluwialny

Mts. The regressive phase is represented by the Komorów and Upper Sławęcin Beds and Drzewica Formation (Tab. 1). In northeastern Poland this cycle consists of the Olsztyn Beds (Bartoszyce IG 1 — Fig. 7).

In the western part of the Polish sedimentary basin this cycle is very well documented by fossils. Early Pliensbachian ammonites characteristic of the *jamesoni* Zone (R. Dadlez, J. Kopik, 1972) and documenting the transgressive phase have been recorded from the Łobez Beds. Within this zone, the *jamesoni* Subzone is also documented in borehole Mechowo IG 1 by the appearance of the ammonite *Uptonia* sp. juv. (*cf. distincta* Tutcher et Trueman) (J. Kopik, 1964; R. Dadlez, J. Kopik, 1972). It is likely that the transgression reached the territory of Poland as early as during the *polymorphus* Zone because it seems that *Hypoxynoticeras sphenonotum* (Monke) found in borehole Gołańcz and poorly preserved, problematic *Peripleuroceras* sp. described from borehole Kamień Pomorski IG 1, come from this zone (R. Dadlez, J. Kopik, 1972). The transgressive phase continued here also during the *ibex* Zone which is evidenced by the appearance of index ammonites in boreholes Rokita IG 1, Mechowo IG 1, Świnoujście 1 and Kamień Pomorski IG 1.

In Western Poland, the *margaritatus* Zone (Chabowo 2 — J. Kopik, unpublished) and *spinatum* Zone (Wolin IG 1) are also documented by ammonites. Between these two well documented shaly parts of the Pliensbachian section (*jamesoni-ibex* and *margaritatus–spinatum* Zones) there are sandstones probably representing the *davoei* Zone but lacking any index fossils so far. Therefore, it is likely that in the extreme west of the Polish Lowlands, two sedimentary cycles instead of one should be distinguished in the Pliensbachian. Insufficient data and lack of sedimentological studies of this zone do not allow drawing such conclusions yet.

Other regions of Polish Lowlands have much worse age documentation. They were dated based on megaspores which ranges point to the Upper Sinemurian and Pliensbachian together.

In the Warsaw Trough, the Pliensbachian is documented by megaspores described by T. Marcinkiewicz. These are: *Horstisporites planatus* (Marcinkiewicz) Marcinkiewicz (= *Maexisporites planatus* (Marcinkiewicz) Marcinkiewicz); *H. harrisi* (Murray) Potonié; *Minerisporites institus* Marcinkiewicz; *Bacutriletes spicatus* (Marcinkiewicz) Marcinkiewicz (M. Franczyk, 1983).

In Kujawy region only in Jeżów IG 1 borehole was found 1 specimen of *B. spicatus* (Marcinkiewicz) Marcinkiewicz.

In northeastern Poland the following megaspores have been described from fluvial deposits: *H. harrisi* (Murray) (= *Erlansonisporites reticulatus*); *H. planatus* (Marcinkiewicz) Marcinkiewicz; *H. harrisi* (Murray) (= *E. reticulatus*) (Bartoszyce IG 1 — R. Dadlez, 1974) and *B. spicatus* (Marcinkiewicz) Marcinkiewicz (Ełk IG 1 — R. Dadlez, 1968).

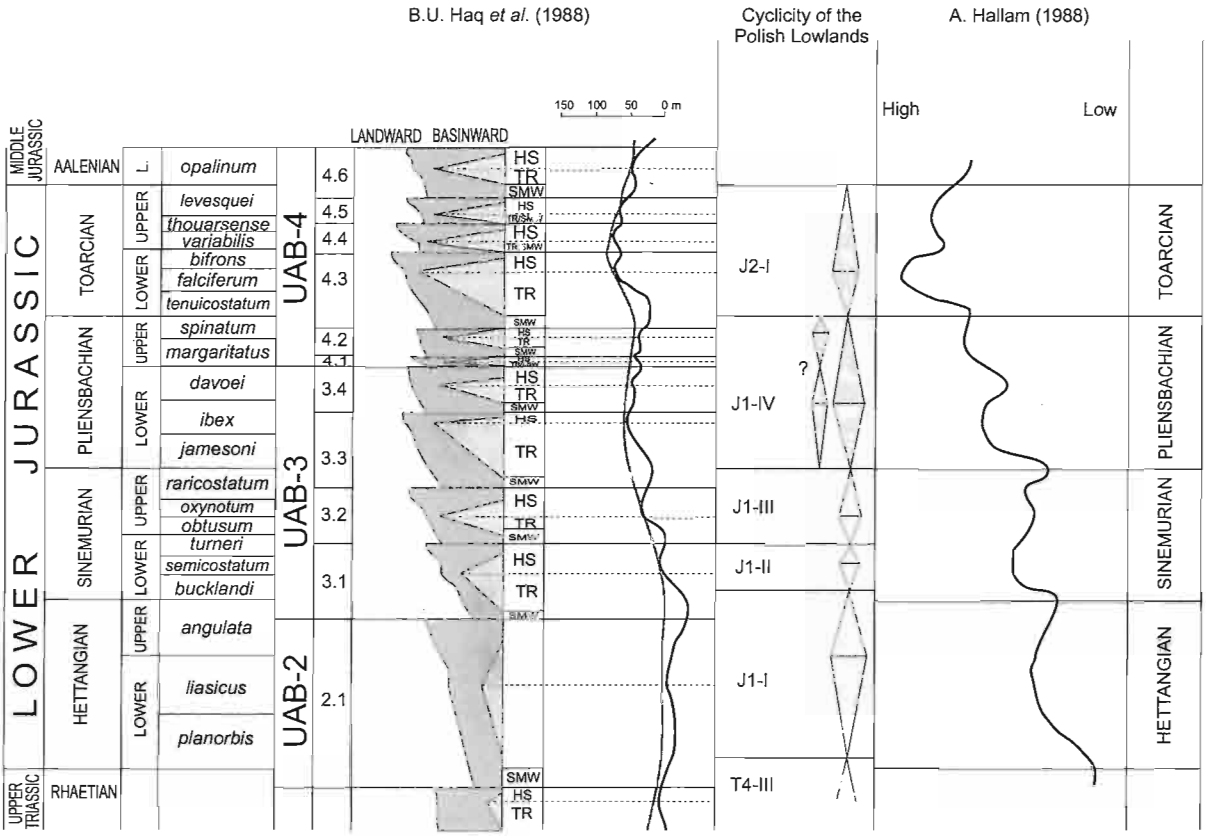

Fig. 9. Transgressive-regressive cycles in Central Poland compared with eustatic curve of B. U. Haq *et al.* (1988) and with eustatic curve of A. Hallam (1988)

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

Cycle J1-IV is subdivided into several 3rd-order cycles in the curve of B. U. Haq *et al.* (1988). The A. Hallam curve (1988), in which only two transgressive-regressive cycles are shown in the Pliensbachian, is more suitable for comparison with the Polish Lowlands (Fig. 9). As it was suggested above, both these transgressions separated by a regression in the *davoei* Zone will possibly be recognized in the extreme western part of Poland.

J2-I. This cycle is correlated with the Toarcian. Its geographical extent is almost equal to the previous one. Its transgressive phase is marked over the whole Polish Lowlands by grey and green mudstones representing brackish basin facies. Only in Pomeranian region it begins with swampy-lagoonal deposits followed by brackish facies. The regressive phase is pronounced by swampy-lagoonal deposits passing upwards into a thick (over 200 m in the Kutno Depression) fluvial complex.

This cycle comprises the middle and upper part of the Gryfice and entire Kamień Beds in Pomerania (Tab. 1, Figs. 4 and 5), and Ciechocinek and Borucice Beds in Central and Eastern Poland (Tab. 1, Figs. 6 and 7).

No index fossils have been found in its transgressive deposits so far. Its age is determined in Western Poland by the appearance of the megaspores: *Paxillitriletes phyllicus* (Murray) Hall et Nicolson (=*Thomsonia phyllicus*), *Erlansonisporites sparassis* (Murray) Potonié (= *E. tegimentus* Marcinkiewicz), *Echitriletes hispidus* Marcinkiewicz, *E. excavatus* Marcinkiewicz, *Bicharisporites scaber* Marcinkiewicz, *Trileites murray* (Harris) Marcinkiewicz, (=*T.* sp. "A") (Mechowo IG 1, Gorzów Wlkp. IG 1 — T. Marcinkiewicz, 1964, 1971).

In the central part of the Polish Lowlands, *Minerisporites institus* Marcinkiewicz recognized by T. Marcinkiewicz (*fide* M. Franczyk, 1983) has been found together with the above-mentioned megaspores.

A similar megaspore assemblage occurs also within the Ciechocinek Beds in northeastern Poland (Kętrzyn 2, Pisz, Ełk — R. Dadlez, 1968; Bartoszyce IG 1 — R. Dadlez, 1974) and in the Holy Cross Mts. margin (Boża Wola, Wyszmontów, Jagodne 1, Zalesie Antonowskie 1, Gutwin and others — T. Marcinkiewicz, unpublished) where the Ciechocinek Beds are also dated by the appearance of index miospores (*Cupressacites subgranulatus* Rogalska; *Undulatisporites undulapolus* Brenner — Ostałów PIG 2, A. Fijałkowska, unpublished).

The fifth Early Jurassic cycle corresponds to four 3rd-order cycles of B. U. Haq *et al.* (1988). It is, however, better correlated with the A. Hallam curve (1988), although this author distinguishes two transgressions in the Toarcian (the second, much weaker, marked in the Late Toarcian, cannot be recognized in sedimentary record in Poland) (Fig. 9).

The above-presented Early Jurassic cyclicity generally corresponds with that published by G. Pieńkowski (1997).

CONCLUSIONS

1. The Early Jurassic sedimentation took place within a shelf and intracontinental basin, alternately. During transgressive phases, largely shallow-shelf heteroliths and sandstones were deposited. Regressive phases were the periods of deltaic, fluvial and swampy sedimentation. Deeper shelf mudstones were deposited only in the transgressive phase of the Pliensbachian cycle J1-IV.

2. Stratigraphy is chiefly based upon megaspores and miospores whose stratigraphical ranges comprise several ammonite zones. Therefore, correlations with various parts of the Polish Basin and the basins of Western Europe are not fully reliable. They are additionally supported by lithostratigraphic and wireline log correlations. Index ammonite fossils enable a comparison with the standard stratigraphical division only in the Pliensbachian of the Pomeranian region.

3. Five 3rd-order transgressive-regressive cycles have been distinguished in the Polish Basin. They fairly well correspond to the cycles in both the B. U. Haq *et al.* curve (1988) and A. Hallam curve (1988) (Fig. 9). Only cycles J1-IV and J2-I comprise a few B. U. Haq's cycles and two A. Hallam's cycles each. Therefore, they may be considered 2nd-order instead of 3rd-order cycles.

Acknowledgements. The author expresses her sincere thanks to Mrs. Elżbieta Tarka and Mr. Jan Turczynowicz for computer drafts.

Translated by Krzysztof Leszczyński

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SYSTEMY DEPOZYCYJNE I ANALIZA CYKLICZNOŚCI W DOLNOJURAJSKIM BASENIE INTRAKRATONICZNYM

Streszczenie

Analizę basenową utworów jury dolnej wykonano na podstawie kilkudziesięciu otworów usytuowanych w bruździe śródpolskiej oraz na jej obrzeżeniach (fig. 1). Otwory z najlepszym materiałem badawczym zostały przedstawione na oddzielnych profilach oraz przekrojach korelacyjnych biegnących poprzecznie do bruzdy: Gorzów Wlkp. IG 1 (fig. 4), Chabowo 2, Mechowo IG 1 (fig. 5), Ustronie IG 1, Jamno IG 1 — linia pomorska (fig. 2) oraz Koło IG 4, Poddębice PIG 2, Krośniewice IG 1 (fig. 6), Gostynin IG 1/1a, Bartoszyce IG 1 (fig. 7) — linia centralna (fig. 3).

W pierwszym etapie badań przeanalizowano osady pod względem genetycznym, co pozwoliło wydzielić systemy depozycyjne: fluwialny (z podsystemami rzek meandrujących i rzek roztokowych), deltowy, bagienny (z podsystemami: bagienno-jeziornym i bagienno-lagunowym), szelfu klastycznego (z podsystemami: szelfu płytszego i głębszego oraz facją szelfu brakicznego).

Na podstawie następstwa pionowego i przejść obocznych wymienionych systemów depozycyjnych dokonano podziału utworów jury dolnej na 5 cykli transgresywno-regresywnych, a najstarsze utwory (hetang dolny) zaliczono do fazy regresywnej ostatniego cyklu triasowego (T4-III) (tab.1).

T4-III. Początek jury dolnej reprezentują osady fluwialne i bagienne, na podstawie megaspor datowane na hetang dolny. Korelacja z basenem niemieckim i południową Szwecją sugeruje, że są to osady poprzedzające powszechną transgresję w zonie *planorbis,* a więc wiekowo muszą być datowane również na tę zonę (G. Pieńkowski, 1991, 1997). Na krzywej B. U. Haqa i in. (1988) jurajska część cyklu odpowiada ciągowi systemów szelfu obrzeżającego (fig. 9).

J1-I. Cykl ten obejmuje pozostałą część hetangu oraz najniższą część synemuru. Fazę transgresywną reprezentują utwory płytszego szelfu klastycznego przykryte utworami deltowymi, a następnie fluwialnymi lub bagiennymi. W wielu rejonach cykl ten datują megaspory *Nathorstisporites hopliticus* Jung oraz miospory. G. Pieńkowski koreluje początek cyklu z transgresją w zonie *planorbis.* Przebieg cyklu zgodny jest z krzywymi B. U. Haqa i in. (1988) i A. Hallama (1988) (fig. 9).

J1-II. Cykl ten datowany jest na synemur dolny. Fazie transgresywnej cyklu odpowiadają utwory płytkiego szelfu klastycznego, natomiast fazie regresywnej utwory lagunowo-bagienne, deltowe lub fluwialne. Cykl ten datują również megaspory *Nathorstisporites hopliticus* Jung. Jest on zgodny z krzywą B. U. Haqa i in. (1988) i A. Hallama (1988) (fig. 9).

J1-III. Cykl ten wiekowo obejmuje synemur górny i rozpoczyna się utworami płytkiego szelfu klastycznego, przykrytymi utworami deltowymi i fluwialnymi. Jest on datowany obecnością megaspory *Maexisporites planatus* (Marcinkiewicz) Marcinkiewicz. Cykl koreluje się z krzywymi B. U. Haqa i in. (1988) i A. Hallama (1988).

J1-IV. Cykl ten obejmuje cały pliensbach i po raz pierwszy cały Niż Polski. Na obszarach, gdzie sedymentacja jest kontynuowana (bruzda śródpolska, obszar szczecińsko-gorzowski), fazę transgresywną cyklu reprezentują iłowce i mułowce głębokiego szelfu klastycznego, w fazie regresywnej przechodzące w utwory piaskowcowo-iłowcowe płytkiego szelfu klastycznego, a następnie utwory deltowe i kończące cykl utwory fluwialne. Na obszarach objętych po raz pierwszy sedymentacją dolnojurajską występują utwory fluwialne.

W Polsce zachodniej cykl ten jest dobrze datowany amonitami przewodnimi poziomów *jamesoni* i *ibex,* a następnie *margaritatus* i *spinatum* (R. Dadlez, J. Kopik, 1972; J. Kopik, dane niepublikowane). W centralnej i północno-wschodniej Polsce fauny przewodniej nie stwierdzono, osady datowane są na podstawie przewodnich megaspor.

Cykl obejmuje kilka cykli trzeciego rzędu na krzywej B. U. Haqa i in. (1988) oraz dwa cykle na krzywej A. Hallama (1988). Jest prawdopodobne, że w Polsce zachodniej możliwe będzie prześledzenie obu transgresji wskazanych na krzywej A. Hallama.

J2-I. Ostatni cykl datowany jest na toars. Ma on prawie tak szeroki zasięg jak cykl czwarty. Fazę transgresywną na całym Niżu Polskim znaczą zielone iłowce i mułowce z wkładkami sztormowymi reprezentujące fację zbiornika brakicznego. Fazę regresywną reprezentują początkowo utwory lagunowo-bagienne, a następnie fluwialne.

Osady cyklu datowane są na podstawie przewodnich megaspor i miospor.

Ostatni cykl dolnojurajski odpowiada czterem cyklom trzeciego rzędu na krzywej B. U. Haqa i in. (1988). Jest on bardziej zgodny z krzywą A. Hallama (fig. 9).

Przedstawiony model cykliczności generalnie jest zgodny z modelem opublikowanym przez G. Pieńkowskiego (1997).