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The epicontinental Lower Jurassic of Poland

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I dedicate this work to the Memory of
Dr Władysław Karaszewski (1911–2003),
an outstanding scientist and a worthy Man.

Pracę tę dedykuję Pamięci
Docenta Doktora Władysława Karaszewskiego (1911–2003),
wybitnego badacza i zacnego Człowieka.

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Abstract: During the Early Jurassic times terrigenous, continental, marginal-marine and marine sediments up to 1400 m in thickness were deposited in a large epeiric basin extending across Poland. These strata are defined herein as the Kamienna Group, which is subdivided into 12 newly distinguished or re-defined lithoformations (Fm.). Two new members (Mb.) are also defined. Detailed study of exposures and 35 fully cored boreholes has integrated data from lithology, sedimentary structures, trace fossils, body fossils, boron content, clay minerals and palynology. This has allowed lithofacies description, recognition of depositional systems and subsystems and determination of their fluctuation in space and time leading to a high-resolution sequence stratigraphic analysis. Sedimentation in the shallow, epeiric Early Jurassic basin of Poland was particularly sensitive to reflect changes in sea level. Analyses of accommodation space within regular progradational successions associated with highstand systems tracts shows that the Early Jurassic basin in Poland was generally not deeper than some tens of meters, most frequently it was less than 20 m deep. Except for the ammonite-bearing Pliensbachian deposits in Western Poland, biostratigraphical resolution in marginal-marine and continental deposits is usually of a lesser precision. However, an internally consistent sequence stratigraphic scheme of Poland can be compared with fossiliferous marine sediments of the Ligurian cycle of United Kingdom and France. The minor sequences identified within the Ligurian cycle play very important role in correlation as they can be recognised in the Polish Basin, although they may show some differences in dating and range. In the Polish Basin, lowstand (LST) and falling stage systems tract (FSST) correspond with erosion/non deposition stages at the sequence boundaries. Concerning the range of sea level changes, the Exxon model was also adopted and ten of the Exxon Early Jurassic depositional sequences were identified in the Polish Lower Jurassic and are labelled I–X. Transgressive systems tracts prevail in sedimentary record and are represented either by retrogradational or aggradational facies architecture, and high-stand systems tracts are represented by progradational facies architecture. Parasequence boundaries (flooding surfaces) were defined based on careful regional/spatial facies analysis. A marginal-marine parasequence is usually more complex than a simple “quick flooding- gradual prograding” model, conventionally interpreted in the marine basins. Due to common preservation of transgressive deposits within marginal-marine parasequences, besides the well-defined flooding surfaces the “parasequence maximum flooding surfaces” were distinguished. The best correlative horizons, particularly in the basin centre, are represented by sequence boundaries, while the maximum flooding surfaces or their correlatives are well identifiable in the marginal parts of the basin. Intensity and frequency of erosional processes in the marginal parts of the basin mean that depositional sequence boundaries are difficult to recognise because of “amalgamation” of stacked and highly reduced depositional sequences. Correlative significance is of transgressive surfaces is enhanced when they are coupled with their nonmarine correlative surfaces. Development of transgression with its coeval effects in continental deposits is discussed and non-marine correlative surfaces of the transgressive surfaces are documented. Once recognised and arranged, sequences and parasequences in the marginal basins (like the Polish Basin) can help to solve some problems concerning identification and range of major bounding surfaces and systems tracts in open marine basins in Europe, particularly in the Early Toarcian. The regional cross sections and cross sections of the whole Polish Basin showing dominant depositional systems and sequence stratigraphic correlation, as well as “time-tuned” palaeogeographical maps of the Polish Basin in Early Jurassic are presented. Subsidence varied through time along the Mid-Polish Trough, between the Holy Cross Mts and Pomerania. In Hettangian and Late Sinemurian the subsidence rate was higher in the Holy Cross Mts and lower in Pomerania region, while in Early Sinemurian and Early Pliensbachian times the situation was opposite. Despite existence of some regional dislocation zones occurring along the edges of the Mid-Polish Trough, which shaped the sedimentation and sediment thickness contrast (for example the Nowe Miasto–Iłża fault), a gradual decrease of sediment thickness outwards the axis of the Mid-Polish Trough prevails. Additionally, occurrence of conspicuous zones of increased subsidence, which are actually perpendicular to the Mid-Polish Trough (for example the "Mazurian Way"), there is no reason to regard the Mid-Polish Trough in any respect as a "rift basin", at least in the Early Jurassic times.

Key words: continental and marginal-marine depositional systems, sea level changes, sequence analysis, sequence stratigraphic correlation, Lower Jurassic, Poland.

Abstrakt. We wczesnej jurze, w rozległym epikontynentalnym basenie rozciągającym się na obszarze Polski, osadziło się do 1400 metrów utworów terygenicznych pochodzenia lądowego, marginalno-morskiego i morskiego. Utwory te są zdefiniowane w niniejszej pracy jako Grupa Kamiennej (Gr.), która została podzielona na 13 nowo wyróżnionych lub zredefiniowanych litoformacji (Fm.). Wyróżniono też dwa nowe ogniwa (Mb.). Szczegółowe badania obejmujące dane litofacjalne, petrologiczne, ichnologiczne, paleontologiczne, geochemiczne i palinologiczne przeprowadzono w odsłonięciach i 35 pełnordzeniowanych otworach wiertniczych. Pozwoliły one na wyróżnienie litofacji, interpretację systemów i subsystemów depozycyjnych oraz ich czasoprzestrzennej zmienności, a następnie na przeprowadzenie wysokorozdzielczej analizy sekwencyjnej. Wczesnojurajska sedymentacja w płytkim, epikontynentalnym basenie Polski w sposób szczególnie wyraźny odzwierciedlała zmiany poziomu morza. Analiza przestrzeni akomodacji depozycyjnej w obrębie regularnych sukcesji progradacyjnych ciągów systemowych stabilizacji wysokiego poziomu morza (HST) wskazuje, że głębokości wczesnojurajskich zbiorników sedymentacyjnych Polski nie przekraczały wartości rzędu kilkudziesięciu metrów, a najczęściej były to głębokości maksymalnie do 20 metrów. Z wyjątkiem morskich utworów pliensbachu na Pomorzu, które zawierają amonity, podział biostratygraficzny marginalno-morskich i lądowych utworów dolnej jury charakteryzuje się na ogół słabą rozdzielczością. Mimo to, spójny podział stratygraficzno-sekwencyjny dolnej jury w Polsce pozwala na jego porównanie ze schematami sporządzonymi dla bogatych w skamieniałości przewodnie utworów dolnej jury cyklu liguryjskiego w Wielkiej Brytanii i Francji. Zwłaszcza sekwencje krótkookresowe wyróżnione w obrębie tego cyklu są przydatne w korelacji sekwencji, ponieważ są one rozpoznawalne w basenie polskim. Ciągi systemowe niskiego poziomu morza (LST) i ciągi systemowe opadającego poziomu morza (FSST) odpowiadają czasowo w basenie polskim lukom związanym z erozją lub brakiem depozycji na granicach sekwencji. Jeśli chodzi o skalę zmian poziomu morza, również model Exxon Research Group okazał się przydatny do przeprowadzenia korelacji, a dziesięć „exxonowskich" sekwencji depozycyjnych (I–X) zostało wyróżnionych w obrębie utworów dolnojurajskich basenu polskiego. W zapisie osadowym dominują utwory transgresywnych ciągów systemów i są one reprezentowane zarówno przez retrogradacyjne jak i agradacyjne sukcesje facjalne. Utwory ciągów systemowych stabilizacji wysokiego poziomu morza odpowiadają wyłącznie progradacyjnym, regresywnym sukcesjom facjalnym. Granice parasekwencji w obrębie sekwencji depozycyjnych zostały zdefiniowane na podstawie dokładnej czasoprzestrzennej analizy facjalnej w poszczególnych regionach. Parasekwencje marginalno-morskie mają na ogół bardziej złożoną architekturę depozycyjną, niż przyjmowano do tej pory w prostym schemacie szybkiego zalewu i stopniowej, powolnej progradacji. Konieczne było wyróżnienie powierzchni maksymalnego zalewu dla poszczególnych parasekwencji, występują one w różnych odległościach od powierzchni zalewu będących dolnymi granicami parasekwencji. Najlepszymi powierzchniami korelacyjnymi w centrum basenu są granice sekwencji, podczas gdy w obszarach marginalnych najłatwiej wyróżnić powierzchnie maksymalnego zalewu i ich odpowiedniki. W marginalnych partiach basenu sedymentacyjnego częstotliwość i intensywność erozji oraz niewielka subsydencja powodowały często nakładanie się na siebie poszczególnych sekwencji i ich granic, co utrudnia ich wyróżnianie i korelację. Dokładność korelacji powierzchni transgresji zwiększa się, kiedy są one skorelowane z ich lądowymi odpowiednikami. Udokumentowano szczegółowo rozwój transgresji i efekty tego procesu na sąsiadujących obszarach lądowych i podano kryteria wyróżniania niemorskich, korelatywnych odpowiedników powierzchni transgresji. Określona w polskim basenie sedymentacyjnym sukcesja sekwencji i parasekwencji może być pomocna w rozwiązywaniu problemów związanych z identyfikacją i zasięgiem głównych granic korelacyjnych i ciągów systemowych w pełnomorskich, głębszych basenach Europy, co szczególnie przydatne okazało się dla utworów wczesnego toarku. Wykonano regionalne oraz ogólnopolskie przekroje stratygraficzno-sekwencyjne basenu wczesnojurajskiego w Polsce wraz z mapami sporządzonymi dla konkretnych, czasowych powierzchni korelacyjnych, które przedstawiają zmienność czasowo-przestrzenną dominujących systemów depozycyjnych. Tempo subsydencji wzdłuż bruzdy środkowopolskiej zmieniało się w czasie, wykazywało też fluktuacje regionalne — w hetangu i późnym synemurze tempo subsydencji w segmencie świętokrzyskim bruzdy śródpolskiej było większe niż w segmencie pomorskim, a we wczesnym synemurze i wczesnym pliensbachu sytuacja była odwrotna. W pliensbachu i toarku zaznaczały się strefy zwiększonej subsydencji usytuowane prostopadle do rozciągłości bruzdy śródpolskiej (tak zwana „droga mazurska"). Wzdłuż krawędzi bruzdy istniały regionalne strefy dyslokacyjne, wywierające wpływ na sedymentację i kontrast miąższości (np. strefa Nowe Miasto–Iłża). Biorąc jednak pod uwagę na ogół stopniowe zmniejszanie się miąższości osadów na zewnątrz od osi bruzdy i wspomniane strefy zwiększonej subsydencji prostopadłe do osi bruzdy śródpolskiej, nie można w żaden sposób wiązać wczesnojurajskiego etapu rozwoju bruzdy śródpolskiej z procesami ryftowania.

Słowa kluczowe: kontynentalne i marginalno-morskie systemy depozycyjne, zmiany poziomu morza, analiza sekwencyjna, korelacja stratygraficzno-sekwencyjna, dolna jura.

INTRODUCTION

Early Jurassic deposits in Poland occur in two different regions: one is a vast epicontinental basin of the Polish Lowlands and the Polish Uplands, the second is represented by overthrusted, geosynclinal deposits belonging to the Tethys realm (Carpathians — Tatra Mountains and Pieniny Klippen Belt). This paper deals with the epicontinental Early Jurassic deposits, representing the vast majority of the Early Jurassic sediments in Poland (Fig. 1).

The Lower Jurassic sediments in the epicontinental basin of Poland developed as the platform type association of the terrigenous deposits. They are represented by siliciclastic terrigenous sediments with thin, subordinate intercalations ofsiderite, lignite and very rarely dolomites or limestones. Sedimentology, lithofacies, ichnofacies, as well as sequence stratigraphy have been a main pursuit of the present author's studies over more than two decades (Pieńkowski, 1980, 1983, 1984, 1985, 1988, 1991a, 1997, 1998; Pieńkowski, Gierliński, 1987; Gierliński, Pieńkowski, 1999). Most of these papers concerned Hettangian and Sinemurian deposits in the Holy Cross Mts region. One paper (Pieńkowski, 1988) focused on the Pliensbachian and Toarcian deposits of the Częstochowa region. In another paper (Pieńkowski, 1997), a preliminary outline of the Early Jurassic sedimentation in Poland has been presented, but it was based on very limited data. Since then, important new material has been obtained and new publications created much better opportunities for detailed sequence strati-

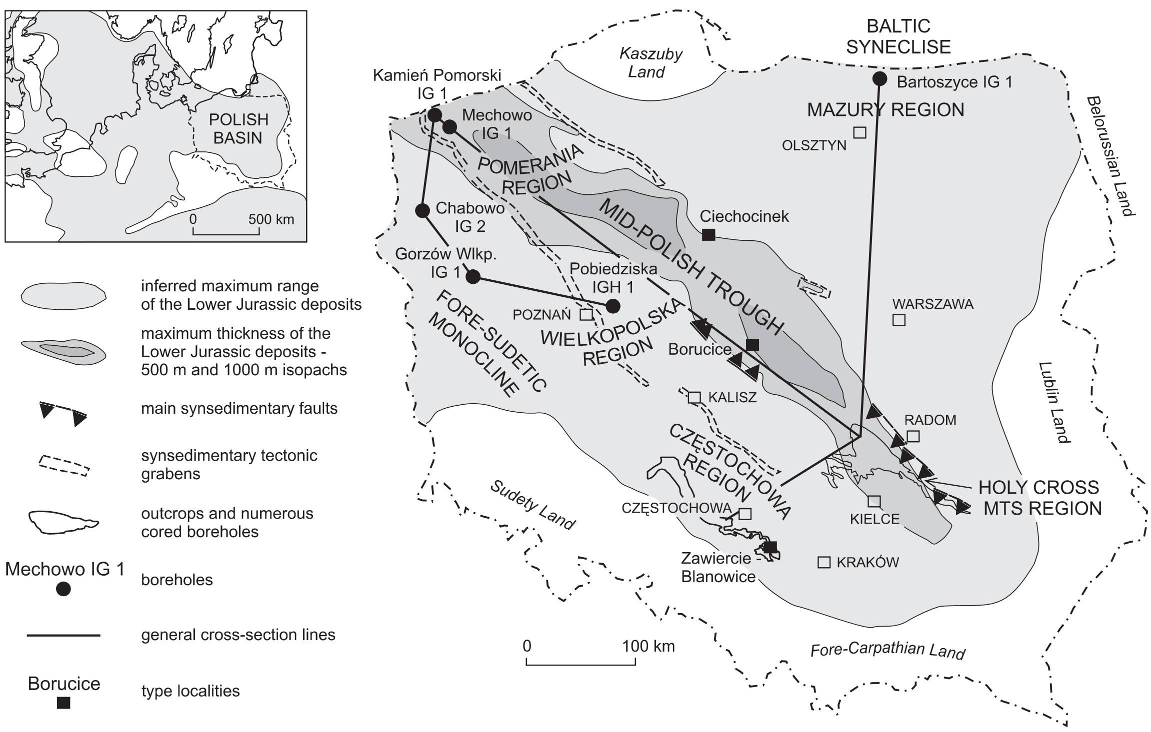


Fig. 1. General distribution of the Early Jurassic deposits and main regions described herein

graphic correlation (particularly, the volume "Mesozoic and Cenozoic Sequence Stratigraphy of European Basins" — de Graciansky, Hardenbol, Jacquin, Vail, Eds., 1998, *Soc. Econ. Paleont. Min., Spec. Publ.*, 60 and "The Jurassic of Denmark and Greenland" — Ineson, Surlyk, Eds., 2003, *Geol. Surv. Denmark, Bull.* 1).

The scope of the present paper can be recapitulated as follows:

- summary of the all the existing data, including new data obtained in the past few years;
- detailed, integrated sedimentological interpretation of the existing material;
- interpretation of depositional systems and their evolution in space and time with respect to local and regional tectonics;
- interpretation of depositional sequences and parasequences;
- new lithostratigraphic subdivision;
- new, “time-tuned” palaeogeographical maps of the selected regions and the whole country;
- new sequence stratigraphic correlation with modern stratigraphic results from Europe.

With regard to method, this study embraces classical sedimentological investigations of lithofacies and analyses of ichnofacies, chemofacies and palynofacies. As far as concerns borehole material, only fully cored boreholes were studied (with one exception of the Kamień Pomorski IG 1 borehole, where the core recovery was 30 %). Wire-line logs, (most of them produced twenty or more years ago) are practically useless for sedimentological studies. Recognition of depositional systems and subsystems was based mainly on the exposures and shallow, fully cored boreholes from the Holy Cross Mts region. The second important region is Częstochowa, where numerous shallow, fully cored boreholes were available. The rest of the country, including the Pomerania region, where studied based on several fully cored boreholes and biostratigraphical data obtained from the previous work. Regional development of sedimentation is presented on profiles, cross sections and maps, and a new sequence stratigraphic scheme suggested which can be compared both with the Exxon curve and with new relative sea level curves and sequence stratigraphic schemes from Western Europe (the volume “Mesozoic and Cenozoic Sequence Stratigraphy of European Basins” — de Graciansky, Hardenbol, Jacquin, Vail, Eds, *op. cit.*).

PREVIOUS WORKS ON THE EPICONTINENTAL EARLY JURASSIC OF POLAND

TECTONIC SETTING

Lower Jurassic deposits occurring in the Polish Basin were formed in the eastern arm of the Early Jurassic NE European epicontinental basin. The zone of maximum thickness runs approximately from west part of Pomerania region (NW) to the Holy Cross Mts (SE) and is called the Mid-Polish Trough (Fig. 1). Maximum thickness of the Early Jurassic deposits in the Polish Basin exceeds 1300 m in the depocentre in the Kutno depression of the Mid-Polish Trough (Feldman-Olszewska, 1997, 1998) and wedges out to 0 meters to NE, SW and SE directions. It was since the beginning of Early Jurassic that the conspicuous axial zone of the Polish Basin was finally placed along the Mid-Polish Trough and remained there for 150 million years until its inversion. Therefore, the Early Jurassic deposits commence the major geological cycle in the epicontinental basin of Poland. The Mid-Polish Trough (of which the recent regional tectonic unit — the Mid-Polish Swell — emerged in the earliest Paleogene), is one of many inverted basins recognised in Western and Central Europe (Ziegler, 1990). It is the largest of these basins, with a length of more than 700 km and a depth of the order of 10 km, and was initiated as an elongated sedimentary basin in the latest Permian due to thermal subsidence and densification of the lower crust coupled with extensional and transtensional tectonic stresses and rapid changes of the crust thickness along the south-western border of the East-European Craton (Dadlez, 1997, 2000, 2001; Dadlez *et al.*, 1995). Interestingly, the Mid-Polish Trough runs generally along the Teisseyre-Tornquist Zone (TTZ) and the Trans-European Suture Zone (TESZ), which shows that the particular crustal rheology contrast (weakness zone) played a significant role in its development (Poprawa, 1997; Królikowski *et al.*, 1999). According to Poprawa (1997), transtentional reactivation of both the main depocentre along the TTZ (50–90 m/Ma) and the secondary depocentre to the SW (separated by a local uplift) occurred during the Hettangian–Early Sinemurian. It was probably related to minor strike-slip reactivation of the TTZ. For the rest of the Early Jurassic, subsidence rates of both depocentres subsequently decreased. The boundaries of the Mid-Polish Trough were in places controlled by the synsedimentary fault zones or narrow tectonic grabens — such as the Koszalin–Chojnice Graben, Laska–Poznań Graben, Kalisz–Kamieńsk Graben (Dadlez, 2001) and the Nowe Miasto–Iłża Fault (Hakenberg, Świdrowska, 1997). This latter fault-zone was active in the Early Jurassic times and in the same time it constituted the northeastern boundary in the Holy Cross Mts segment of the Mid-Polish Trough. However, in most cases a gradual thickness increase towards the axis of the Mid-Polish Trough may be observed (Dadlez *et al.*, 1995; Dadlez, 2001), which can be also explained by a decoupled style of the sedimentary basin (Withjack, Calloway, 2000; Krzywiec, 2002). Tectonic movements, and displacement of rock salt masses of the Late Permian age, both taking place mainly at the end of Late Toarcian, resulted in formation of paleostructures of different order, whose characteristic general arrangement follows the NW–SE orientation (Deczkowski, Franczyk 1988).

BIOSTRATIGRAPHY

Scarcity of sediments containing marine or brackish-marine fauna was claimed by most of the researchers as the main problem in establishing precise stratigraphy of the Early Jurassic deposits in Poland. However, results of successive studies allowed creation of a stratigraphic framework, although it shows substantially varied precision, both between the regions and in geological time (Fig. 2). Most valuable in this respect were finds of ammonites, but so far they have only been reported from the west part of Pomerania region and only from the Pliensbachian deposits. In a series of papers (Kopik, 1962, 1964; Dadlez, Kopik 1972; Kopik, Marcinkiewicz, 1997) the successive finds of ammonites were documented. So far, four standard biochronozones (Fig. 2) have been distinguished: *jamesoni* (with *polymorphus*, *brevispinum*, and

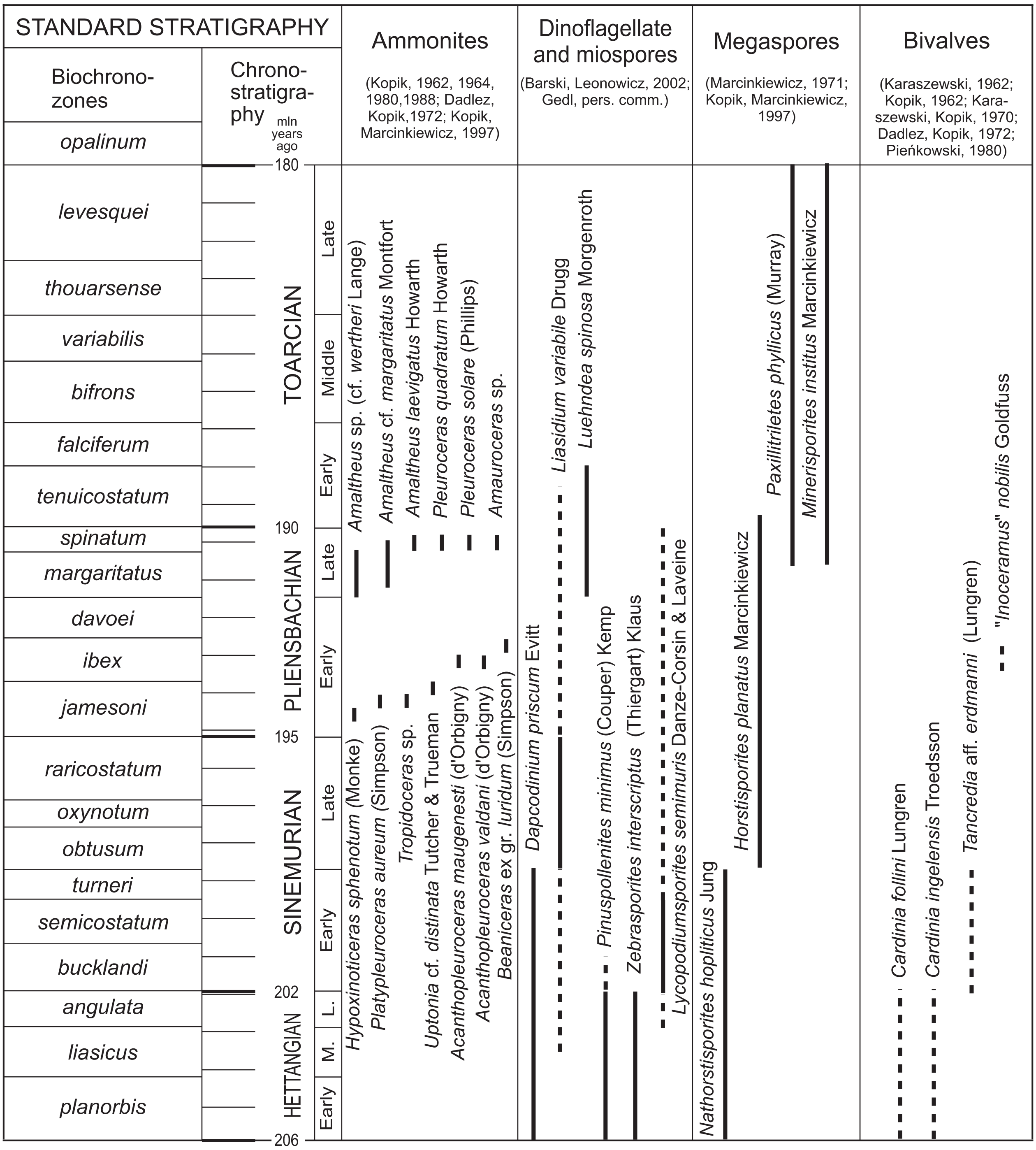


Fig. 2. Biostratigraphy of the Early Jurassic deposits in Poland

jamesoni subzones), *ibex* (with *valdani* and *luridum* subzones), *margaritatus* (no subzones specified) and *spinatum* (with *apyrenum* Subzone) — Fig. 2. It is worth mentioning, that the ibex Zone is most complete and documented by most numerous and diversified ammonites. Moreover, the range of deposits containing ammonites of the *ibex* Zone is most extensive of all ammonite-bearing deposits in Pomerania (Dadlez, Kopik, 1972).

Next, finds of dinoflagellate cysts, particularly *Luehndea spinosa* (Morgenroth) defines the stratigraphic position (Barski, Leonowicz, 2002) of the lower part of the Ciechocinek Formation in Kozłowice and Boroszów exposures (Częstochowa region). This palynomorph occurs between, inclusively, the *margaritatus* Zone (Upper Pliensbachian) and *tenuicostatum* Zone (Lower Toarcian). Other dinoflagellate cysts are also reported, but they are of lesser stratigraphic significan ce (Fig. 2). Noteworthy dinoflagellate cysts of the Liasidium, *Mendicodinium* and *Nannoceratopsis* genera were reported from several horizons of the Early Jurassic deposits in the Fore-Sudetic Monocline (Gorzów Wielkopolski IG 1 borehole; Gedl, pers. comm.), but their stratigraphic significance is yet to be worked out. Occurrence of *Dapcodinium priscum* Evitt was noted in the Hettangian strata (Gliniany Las 1 borehole) of the Holy Cross Mts region (Barski, pers. comm). Generally, dinoflagellate cysts have the best palynostratigraphical resolution potential in marine Jurassic sediments, but unfortunately from the Toarcian onward (Riding, Ioannides, 1996). Additionally, a number of forms generally assigned to Acritarcha occur in Early Jurassic deposits, although these are of little stratigraphic significance (Pieńkowski, Waksmundzka, 2002).

Early Jurassic bivalves (Pl. I, 1–12) are of a lesser stratigraphic significance than palynomorphs due to the general longeitivity of bivalve genera in geological time. The other problem is connected with their generally poor preservation and, consequently, difficulties with their precise determination. Bivalve fossils in the epicontinental Lower Jurassic of Poland have been recorded from marine, brackish-marine and continental deposits (Karaszewski, 1962; Kopik, 1962, 1988, 1998; Karaszewski, Kopik, 1970; Dadlez, Kopik, 1972; Pieńkowski, 1980, 1983, 1997; Kopik, Marcinkiewicz, 1997). Only few forms have been reported to have any stratigraphical significance (Fig. 2). The earliest forms of some disputable stratigraphic value are represented by Cardiinidae — *Cardinia follini* Ludgren (Pl. I, 8) and *Cardinia ingelensis* Troedsson. In his monograph on Early Jurassic deposits of Scania, Troedsson (1951) assigned both forms to Lias alpha 1 and alpha 2 (Hettangian). Although it is not definitely confirmed if the mentioned bivalves truly existed in such a narrow time interval only, it is fact that neither *Cardinia follini* Ludgren nor *Cardinia ingelensis* Troedsson have been found in deposits younger than Hettangian. Rapid world-wide migrations of representatives of environmentally opportunistic representatives of *Cardinia* in the earliest Jurassic times, which was associated with breaking up of Pangea (Krobicki, 2001), could substantially increase the rate of their radiation. Therefore, it is possible that during that remarkable period in evolution of the Cardiinidae family, many short-lived genera of *Cardinia* could appear and they may be of a biostratigraphic importance. Another form of possible stratigraphic significance is *Tancredia erdmanni* (Lundgren) (Pl. I, 12), an endemic form reported from Sinemurian deposits of Scania (Kopik, 1962), as well as other forms like *Cardinia phillea* d'Orbigny, *Pleuromya* forchhammeri Lund, *Nuculana* (*Dactryomya*) *zieteni* Brauns, *Pronoella* cf. *elongata* Cox (Pliensbachian). Bivalves may be tentatively used as auxiliary stratigraphic tool, but their greatest significance is in palaeoenvironmental interpretation.

Foraminifera also are generally of a poor stratigraphic significance, but they provide valuable palaeoenvironmental information (Kopik, 1960, 1964; Jurkiewiczowa, 1967; Karaszewski, Kopik, 1970; Dadlez, Kopik, 1972). The rich foraminifera assemblage from the marine deposits of Early Pliensbachian age from Pomerania is dominated by Nodosariidae. Primitive agglutinating forms are indicative of the penetration of the inland basin by marine transgressions the intensity of which were, however, too small to change radically the existing physico-chemical conditions of the aquatic environment (Kopik, 1988).

In continental and marginal-marine deposits the main stratigraphic indices are megaspores (Marcinkiewicz, 1971, 1988). The stratigraphic framework based on megaspores is based on material from boreholes in Pomerania region, where intercalations of deposits with marine fauna allow correlation of the megaspore ranges with index marine fossils. Marcinkiewicz (1988) proposed three megaspore assemblages (*Nathorstisporites hopliticus* assemblage, *Horstisporites planatus* assemblage and *Paxillitriletes phyllicus* assemblage), dividing the Early Jurassic into the three megaspore zones (Hettangian–Early Sinemurian, Late Sinemurian–Pliesnbachian and Toarcian, respectively). These assemblages are characterised by a predominance of one or two species, with a simultaneous presence of other megaspores in smaller numbers (Fig. 2).

Miospores (bisaccate pollen and spores) are of regional stratigraphic significance, particularly in the Hettangian–Sinemurian strata (Lund, 1977; Dybkjær, 1988; 1991; Waksmundzka, 1998; Ziaja, 1991; 2001). Occurrences of the pollen species *Pinuspollenites minimus* (Couper) Kemp accompanied by *Concavisporites toralis* (Leschik) Nilsson, *Concavisporites divisitorus* Kedves & Simoncsics, *Trachysporites asper* Nilsson 1958, *Dictyophyllidites mortoni* (de Jersey) Playford & Dettmann and *Zebrasporites interscriptus* (Thiergart) Klaus point to the Hettangian age (Lund, 1977; Dybkjær, 1988; 1991 – *Pinuspollenites–Trachysporites* zone). Regular presence of the spore species Lycopodiumsporites semimuris Danze-Corsin & Laveine suggests an Early Sinemurian age (younger than Hettangian) within the *Nathorstisporites hopliticus* zone (Lund, 1977; Dybkjær, 1988; 1991; Pieńkowski, Waksmundzka, 2002 — *Cerebropollenites macroverrucosus* zone). Another miospore which has well established stratigraphic significance is *Aratrisporites minimus* Schulz (Schulz, 1967;

Karaszewski, 1974; Rogalska, 1976; Ziaja, 1991; 2001) which occurs in the Hettangian–Early Sinemurian deposits. Another significant form but of much wider range is represented by *Cupressacites subgranulatus* Rogalska occurring from Pliensbachian to the beginning of Middle Jurassic, and most characteristic for the Toarcian (Rogalska, 1976). Generally, miospores are of a lesser stratigraphic significance in strata younger than the Early Sinemurian (Fig. 2). Miospores play an important role in determining palynofacies and in palaeoenvironmental interpretations (Pieńkowski, Waksmundzka, 2002).

Finds of well-preserved floristic macrofossils (Pl. II, 6) are spotty, except for very common plant roots. Their biostratigraphical significance is of a lesser importance, although some assemblages may be helpful also for stratigraphy (Makarewiczówna, 1928; Wcisło-Luraniec, 1991).

PETROGRAPHY

General petrographical description of lithological types (based mainly on studies in transmitted light and some thermal analyses) has been published by Maliszewska (1967, 1997) and Przybyłowicz (1967). According to the authors, microlithofacies of quartz arenite dominates, accessory minerals are represented by microcline, oligoclase, heavy minerals, biotite, chlorite and rock fragments. Floral detritus is common. Cement is built mainly of illite or kaolinite, sometimes silica, in places siderite is common. Rarely, calcite-dolomite or chamosite cements do occur in the Pomerania region. Kaolinite pseudooids are found in the same area and they represent pseudomorphs after chamosite. Microlithofacies of quartz wacke is less common and it occurs either in the marginal areas of the basin or opposite, in the central parts represented by open-marine deposits.

Mudstones are mainly represented by grey, grey-brown or grey-green quartz mudstones built of illite and subordinate kaolinite. Claystones and shales are also composed mainly of illite and subordinate kaolinite, sometimes admixtures of chlorite and swelling clay minerals (Pieńkowski, 1980, 1983) are present. Characteristic siderite clays occur particularly in the Przysucha Ore-bearing Formation (Upper Hettangian) in the Holy Cross Mts region.

Conglomerates occur in the marginal areas of the Polish Basin and are represented mainly by polymict conglomerates or conglomerates composed of local mudstone/claystone fragments. Heavy mineral composition may bring an answer concerning provenance of sandstones. Rapid change in heavy mineral composition occurs for example in the Pliensbachian deposits in Bartoszyce IG 1 borehole (Maliszewska, 1974). Such a rapid change in heavy mineral composition is interpreted by the present author as a change in sedimentary source area which occurred at the depositional sequence boundary.

LITHOSTRATIGRAPHY AND CYCLIC SEDIMENTATION

Subdivision of the Lower Jurassic deposits in Poland into lithostratigraphic units has been presented and discussed by Dadlez (1978). The main problem in the past was that there were no clear and unified criteria in naming new units — pure "lithostratigraphy" was often mixed with "sedimentary cycles" and sometimes with chronostratigraphy. Lithostratigraphic subdivision of the Lower Jurassic deposits appeared to be difficult even in fully cored boreholes. This can be explained by the fact that the general lithology is usually monotonous (except for the characteristic Ciechocinek Formation), while the lithofacies and depositional systems are actually varied both in space and time. The vast majority of some 1000 boreholes penetrating Lower Jurassic deposits in Poland were not cored or the core recovery was minimal within this interval. Most authors tried to introduce their own units it the regions they studied. In result, over 60 informal lithostratigraphic subdivisions exist in the literature. Deczkowski (1997) presented the latest lithostratigraphical subdivision of the Lower Jurassic deposits of Poland, comprising only those units, which are widely accepted in literature. This scheme (with some corrections and amendments) has been adopted in the present paper as a starting point for preparing the new lithostratigraphical scheme of the Lower Jurassic in Poland (Fig. 3). Dadlez (1978) was first to propose introduction of two Poland-wide formal units — Ciechocinek Formation and Borucice Formation (Toarcian), which are very characteristic. The present author (Pieńkowski, 1997) postulated, that most of the informal "series" introduced by Karaszewski (1962) in the Holy Cross Mts region should be actually named as formations. The new formal lithostratigraphical subdivision is within the scope of the present paper and is presented on the Fig. 3. In the Częstochowa region, the first comprehensive study presenting sedimentation and lithostratigraphy of the Lower Jurassic deposits was that of Znosko (1955), with later stratigraphic revisions (Znosko, 1959; Marcinkiewicz, 1960; Mossoczy, 1961).

Besides lithostratigraphy, development of sedimentary basins and cyclicity of sedimentation were discussed in number of papers. Różycki (1958) subdivided the Early Jurassic deposits in the Kujawy region (central Poland) into six depositional cycles (Fig. 3). A similar approach was adopted by Dadlez (1969) who based the local lithostratigraphic subdivision of the Lower Jurassic in Pomerania on observation of the rhythm of sedimentation (i.e. marine transgressions and regressions, which were inferred mainly from presence of fauna)

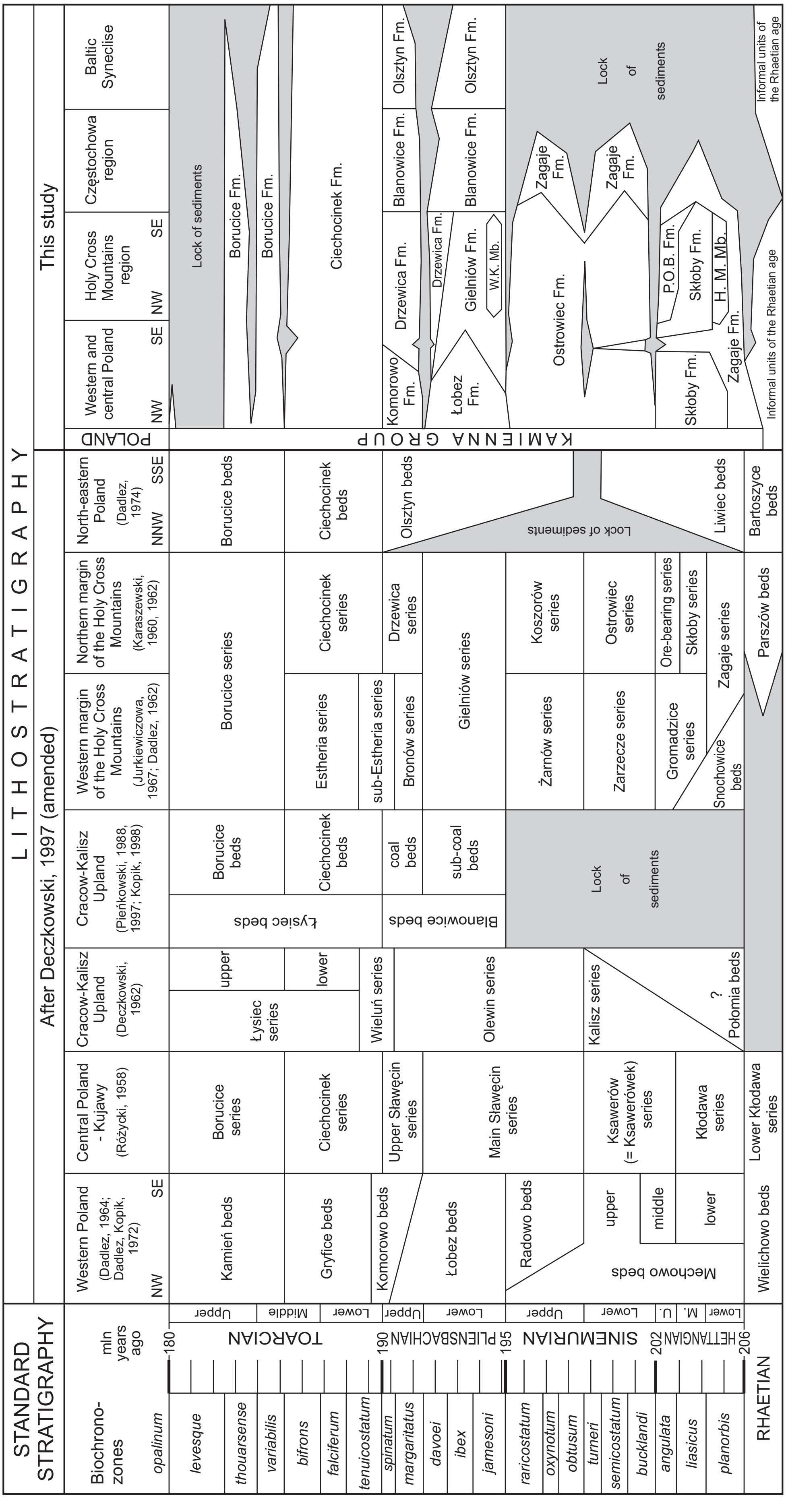


Fig. 3. Lithostratigraphical subdivisions of the Early Jurassic deposits in Poland in the previous works (left) and proposed herein (right)

Abbreviations: P.O.B. Fm. — Przysucha Ore-bearing Formation; H.M.Mb. — Huta Mudstone Member; W.K.Mb. — Wola Korzeniowa Member and on distinction of sedimentary cycles. These cycles were grouped into bigger units called macrocycles or "beds" (Fig. 3). Such an innovative approach indicating "tendencies" in sedimentation marked new step in analysis of the sedimentary basin and could substantially improve stratigraphic correlations. However, in a "pre-sedimentology" era assignment of certain rock bodies to a given "transgressive" or "regressive" tendency was risky and could result in erroneous correlation. For example, the Ore--bearing Series — renamed as Przysucha Ore-bearing Formation — has been regarded by all previous authors as a "transgressive" series, whereas this formation represents a regressive succession — see later discussion in this paper). Dadlez and Kopik (1972) presented an updated reconstruction of the Early Jurassic sedimentation in the Pomerania region, which was mainly based on new ammonite finds and resulted in confirmation of strong diachroneity between the Pliensbachian units (depositional cycles) — the Łobez Beds and the Komorowo Beds. Karaszewski (1962) summarised his studies on the Lower Jurassic deposits in the northern slope of the Holy Cross Mts. He put together all accessible data and proposed stratigraphical and lithostratigraphical scheme which, with some changes, remained up to date. He observed that intensification of marine influence was connected with more numerous trace fossils. This allowed him to present a more precise picture of cyclicity of sedimentation. He also correctly claimed a Hettangian age for the Ore-bearing Series (Karaszewski 1974). Jurkiewiczowa (1967) and Karaszewski, Kopik (1970) gave more complete stratigraphic documentation of the Lower Jurassic deposits in the Holy Cross Mts region. Karaszewski (1971, 1974, 1975) gave also description of invertebrate trace fossils and first dinosaur footprints from Poland. Works of Wyrwicki (1966), Kozydra (1968) and Cieśla (1979) described deposits of Liassic fire clays in the Holy Cross Mts region and gave insights into many aspects of regional geology. Unrug (1962) presented directions of clastic material transport in the Lower Jurassic deposits of this region. However, without genetic studies on the sedimentary structures that he measured, his conclusions about palaeoslopes are misleading. Measurements performed in so called Snocho- wice beds and Połomia beds in the southern part of the Polish Basin gave much more accurate results. In relation to the southern part of the basin, one should mention two works, dealing with transport of clastic material in the so-called Snochowice and Połomia conglomeratic beds (Unrug, Calikowski, 1960; Dadlez, 1962). These conglomerates were deposited in braided river depositional system with transport direction generally from SE to NW. The age of the conglomerates was a matter of controversy and although they were assigned to the Late Toarcian (Kopik, 1998) it is possible that isolated "patches"of conglomerates lying on various Triassic deposits may represent any age from Late Triassic to the end of Early Jurassic.

More recently, Deczkowski (1997) gave an outline of development of sedimentation in the Early Jurassic Polish Basin, which generally followed that of Dadlez (1969, 1978) and Karaszewski (1962). Feldman-Olszewska (1997) has proposed a general outline of depositional cyclicity of the Early Jurassic sedimentation in Poland, and generalised palaeogeographical maps have been presented (Feldman-Olszewska, 1998). However, these represent only very general hypotheses of depositional systems inferred from lithofacies, without actual sequence correlation. With the exception of beds with marine fauna from Pomerania, these interpretations of depositional systems are rather hypothetical.

SEDIMENTOLOGY

Sedimentological studies commenced in the early eighties with the works of the present author (Pieńkowski, 1980 unpubl.; 1983; 1984). They encompassed description of lithofacies (including sedimentary structures) in exposures and shallow boreholes, interpretation of cyclicity of sedimentation and palaeoenvironment, direction of transport of clastic material and preliminary conclusions on eustatic cycles in Hettangian and Sinemurian deposits of the Holy Cross Mts region. A summary of biogenic invertebrate structures from the Lower Liassic deposits was given (Pieńkowski, 1985) and new dinosaur footprints were described (Pieńkowski, Gierliński, 1987; Gierliński, Potemska, 1987). In 1988, a facies analysis of the Pliensbachian-Toarcian deposits in the Częstochowa region was performed (Pieńkowski, 1988). Brański (1988, 1996, 1998) studied in detail clayey formations of the Early Jurassic deposits of the Holy Cross Mts region and prepared quantitative lithofacies maps. Comparative studies between Poland and Sweden resulted in sequence stratigraphic scheme (Pieńkowski, 1991, 1997). In the nineties and beginning of new century, many papers regarding dinosaur footprints from the Holy Cross Mts region appeared (Gierliński, 1990, 1991, 1994, 1995, 1996, 1997, 1999, Gierliński, Pieńkowski, 1999; Gierliński *et al*., 2001a, b). There was also find of a dinosaur nesting ground described by Pieńkowski (1998). A generalised description of depositional systems and depositional sequences of the Early Jurassic deposits is given by Pieńkowski (1997).

METHODS APPLIED IN DESCRIPTION OF EXPOSURES AND BOREHOLES

LITHOFACIES

Following Reading (1986) and Miall (1990), in the present paper lithofacies are understood very broadly, as all the primary depositional attributes observed in beds, such as bedding, grain size (average and maximum), texture and sedimentary structures.

Description of sedimentary structures is based on Collinson and Thompson (1982) and follows the rule that a given lithofacies represents characteristic depositional forms which originated in a certain environment (depositional system or sub-system). Internal structures of different scale observed in sandstones comprise those of sandwave migration (producing tabular cross bedding) and dune migration (producing trough cross bedding) — Harms *et al*., 1975. Horizontal bedding is produced either by upper regime currents or those of lower regime. Characteristic cross stratification is hummocky cross stratification (H.C.S.). Micro-hummocky cross stratification (Pls. III, 4; IV 5; V 2) which was produced during waning storm events (Dott, Bourgeois, 1982) is particularly abundant in heteroliths. Hummocky cross stratification (Harms *et al*., 1975) can be recognisable in the boreholes (Pl. V, 1), because the diameter of the core usually exceeds 12 cm. Hummocky and micro-hummocky cross stratification are indicative sedimentary structures, pointing to a storm-dominated nearshore depositional system (shoreface depositional subsystem, including transition between shoreface and offshore).

The variety of cross lamination resulting from mixed lithologies of sand and mud, called heteroliths, requires some comment. Classification of heteroliths is based on proportions of finer-grained sediment (mud) and sand, and follows Reineck and Wunderlich (1968). More detailed description and classification of mud-dominated heteroliths was given by Schieber (1999). Where fine-grained sediment dominates, sand ripples may occur as isolated ripple form sets forming lenticular bedding (Pl. III, 3, 5). When sandy/silty lamina or lenses occurring in mudstone do not show cross lamination, such type of heterolith is called lenticular lamination (Pls. III, 1–3, 5; IV, 2; V, 3). Such a mudstone lithofacies was described by Schieber (1999) as silt-laminated mudstone (CM-2 lithofacies) characterised by graded, laminated silt layers. Otherwise, when cross lamination in lenses is visible, such heterolith is assigned to lenticular bedding (Pls. III, 3, 5; IV, 1–4). Schieber (1999) assigned such lithofacies to laminated sandy mudstone (SM-1) lithofacies, embracing both lenticular and wavy bedding. Such lithofacies imply alternating current flow and slackwater conditions. Heteroliths of wavy bedding (Pls. III, 4; IV, 2; V, 4, 8) and flaser bedding (Pl. III, 7) types correspond to classical characteristics of those types of heteroliths given by Reineck and Wunderlich (1968). In flaser bedding, the muddy sediment occurs as thin and often discontinuous laminae which drape ripple forms or are confined to ripple troughs (Pl. III, 6, 7). Features of sandy-silty layers such as opposing foresets, draping lamina (micro-hummocky cross lamination) and cross-stratal offshots are interpreted as an indication of wave action (De Raaf *et al*., 1977; Pls. III, 4, 6; V, 4,7).

The scale of an individual lithofacies unit depends on the level of detail incorporated in its definition. In the present work, the lithofacies are defined finely to accommodate the level of detail in the centimeter-by-centimeter logging. Description of the lithofacies is included it the columns 1–7 in borehole profiles and in the exposure profiles (Figs. 4, 4a, 5 CD). For example, a lithofacies set (sandstone bedset) from the interval 82–84 m in the Gliniany Las 1 borehole (Fig. 5 CD) is described as: light-grey, fine-grained, average to well sorted sandstone (there is no or little difference between the average and maximum grain size); horizontal bedding, tabular cross bedding, disturbed bedding; erosion surfaces; fodinichnia, cubichnia and repichnia; rare plant detritus (explanation Fig. 4a).

Taking into account all limitations (Miall, 1996), cyclic (or autocyclic) stratification and event stratification have been recognised as two useful, descriptive terms in characteristics of the Early Liassic sedimentation. Autocyclic sedimentation is characterised by continuous facies evolution within cycles, while event mechanism involves introduction of "event" facies into "background" facies (Strasser, 1991). Both "cycles" and "events" are strictly related to the depositional systems. For example, fining-upward fluvial cycles dominate in alluvial plain (meandering or braided rivers) depositional systems. These cycles were mostly produced by an autocyclic mechanism (the shifting of facies in meandering or braided rivers; Beerbower, 1964). Coarsening-upward cycles dominate in brackish-marine and marine sediments. Again, that cyclicity is attributed to autocyclic processes of sedimentation, i.e. local variations in sediment supply, directions of wind and waves, shifting of delta lobes, migration of spits and barriers, etc. Individual sedimentary cycles reflecting such autocyclic processes are presented in columns 6 and 7 in the borehole columns or in the profiles of exposures and their thickness is usually a few metres, rarely exceeding 10 metres.

Facies/cycles models accepted in the present work were based both on the analysis of existing literature and on the present author's own studies, based in most cases on three-dimensional or at least two-dimensional exposures.

Event stratification is usually regarded as a result of relatively short-time events occurring during "normal", autocyclic sedimentation. However, it is disputable if much longer allocyclic processes occurring in the regional, basin or even world-wide scale still represent "events". Main driving forces of such allocyclic processes are tectonics, climate changes and superregional ocean level changes. For example, regional or world-wide sea level falls are often associated with widespread subaerial erosion or ravinement surfaces, corresponding with sequence boundaries (Strasser, 1991).

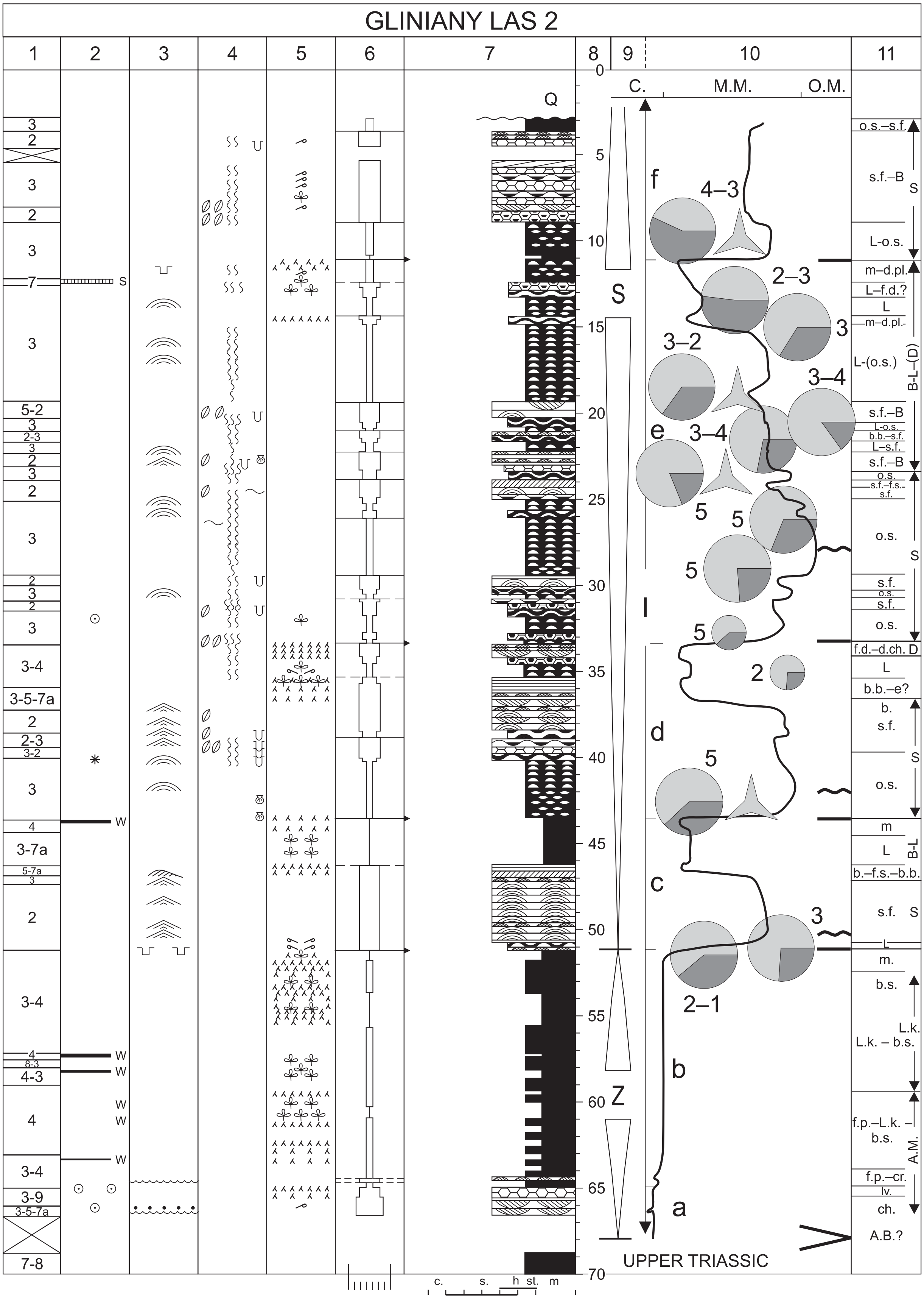


Fig. 4. Gliniany Las 2 borehole profile[1]

[1] All the other borehole profiles (Figs. 5, 18, 19, 21–23, 27, 31–38, 41, 43–45, 47, 50–54, 56–60, 63, 64, 66) are included in the CD insert

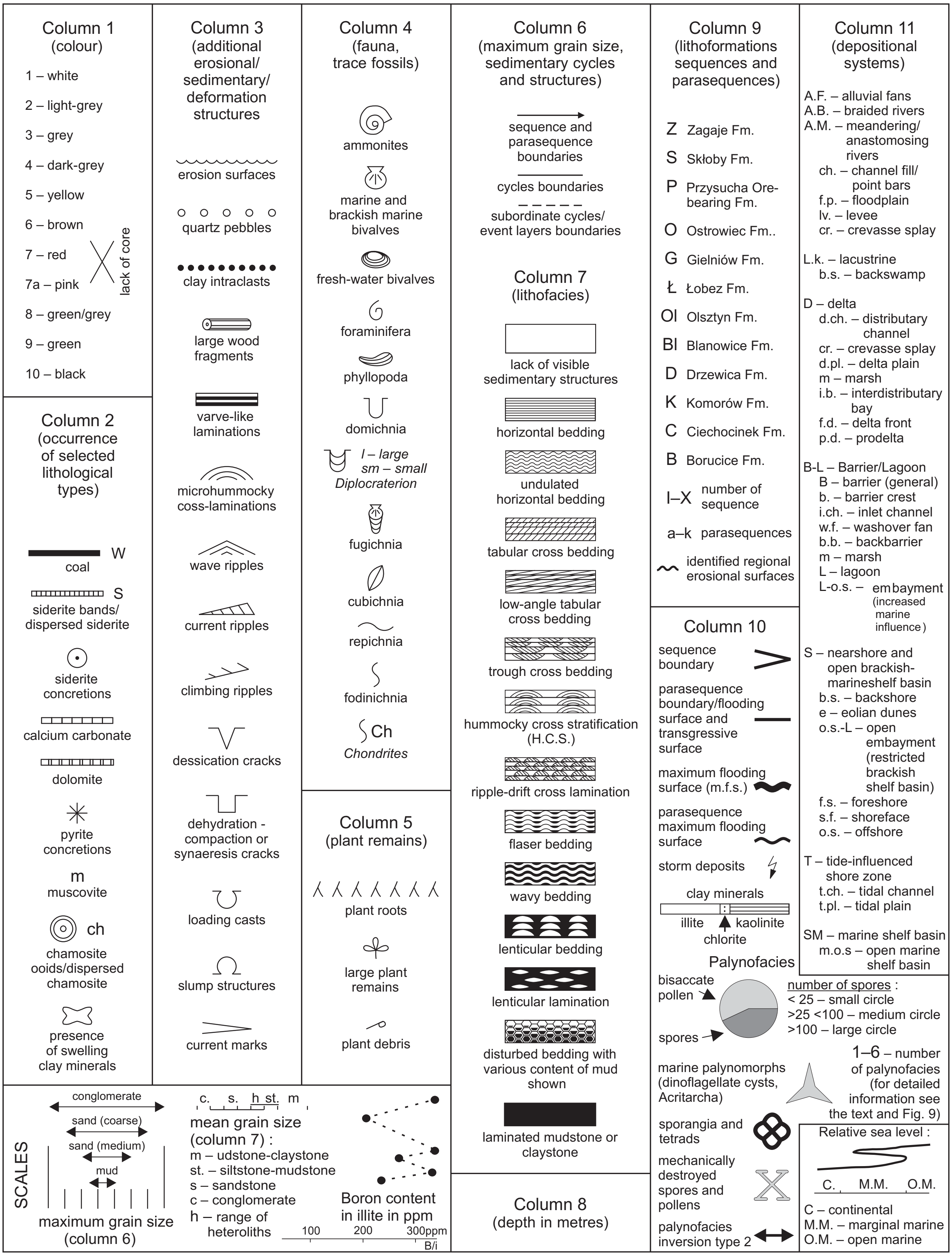


Fig. 4a. The legend explaining lithofacies, ichnofacies, chemofacies, palynofacies, cyclicity of sedimentation, lithoformations, depositional sequences, parasequences and interpretation of depositional systems/subsystems is applicable for all the borehole profiles (see also profiles on CD) and exposures profiles included in this work

Tectonics played a local role and was most clearly related to certain fault zones, which were active during sedimentation (Fig. 1). Subsidence pace in Poland was higher in Hettangian times, compared to the rest of Early Jurassic (Poprawa, 1997), but this is part of a long-time trend. Climate changes were rather insignificant in the Early Jurassic sedimentation in Poland, except perhaps for the earliest Hettangian (Hubbard, Boutler, 2000), although alternative interpretation (McElwain *et al*., 1999) should also be regarded in that respect. The most important allocyclic factor was superregional sea level

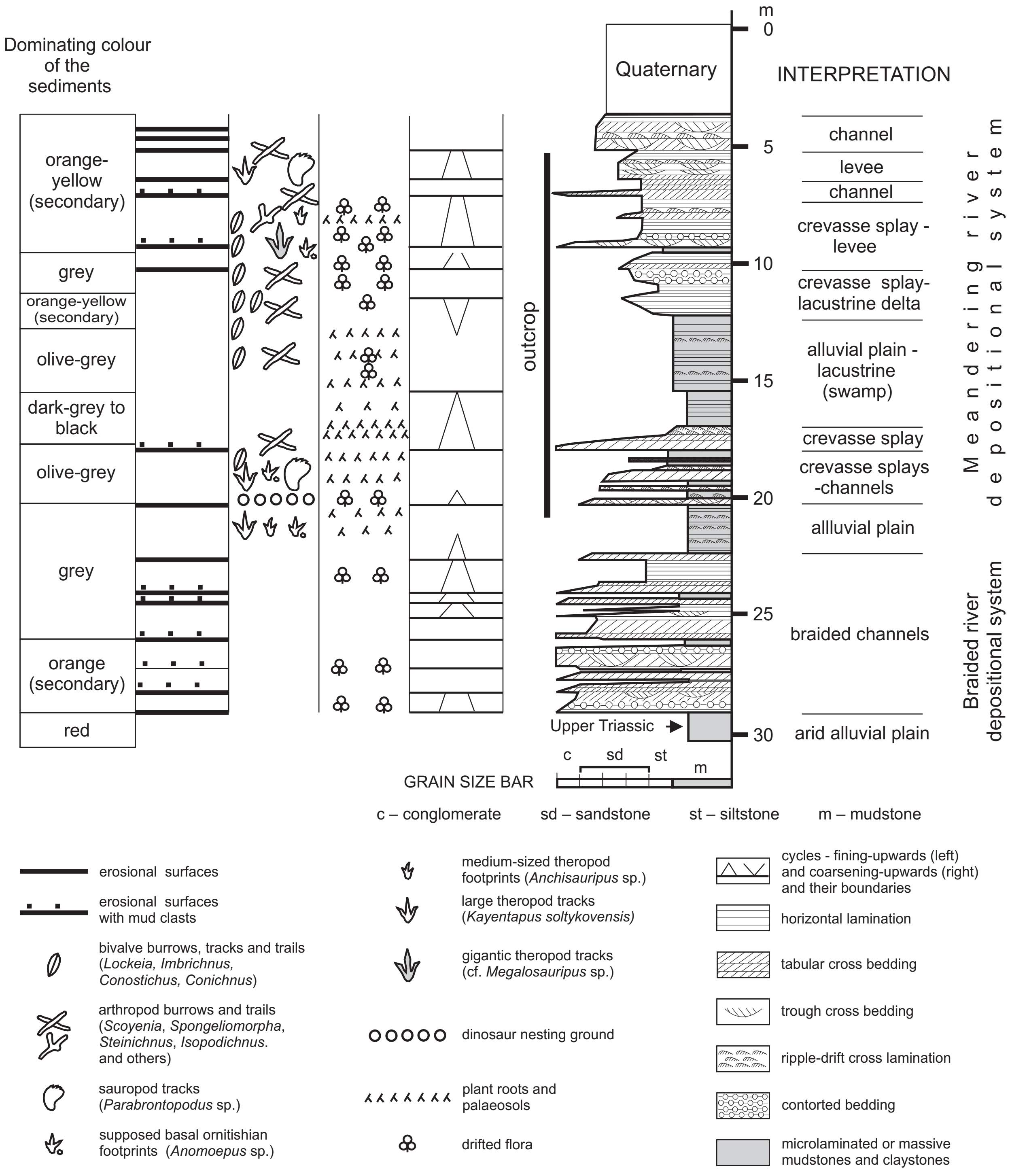


Fig. 6. Profile of the Sołtyków shallow borehole and the interval exposed in the outcrop (marked with the bar) and sedimentological interpretation

Depositional sequence Ia, basal Hettangian, the lowermost Zagaje Formation (See also: Pl. I, 1 — Unionoidea Pl. VII, 1, 2, 5, 6 — large or giant theropod and sauropod footprints; Pl. VII, 4a, b — *Lockeia czarnockii* (Karaszewski) and Pl. XII, 1)

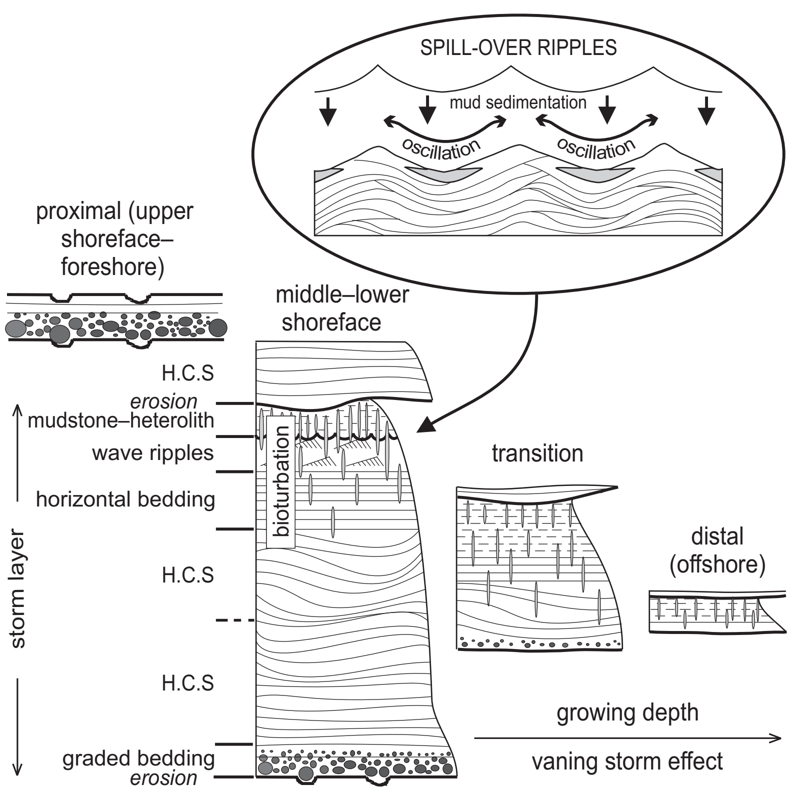


Fig. 7. Storm cycles in shoreface and offshore depositional subsystems of the Lower Jurassic in Poland

Based on Dott and Bourgeois (1982) with some amendments. Sketch of the spill-over ripples is based on description of Seilacher (1982). H.C.S. — hummocky cross stratification. Note that the sketch presents "ideal" storm cycles. Availability of coarse-grained sediments is crucial for presence of graded bedding, ensuing erosion commonly removes upper parts of the storm layers, and heavily bioturbation may obliterate primary sedimentary structures. Thus, the occurrence of truncated layers with hummocky cross stratification or less frequently horizontal bedding is common in shoreface and transition zones, while the storm layers homogenised by bioturbation are common in the distal (offshore) zone

changes, which controlled formation of depositional sequences and parasequences. This subject will be discussed in the next chapters of this paper.

Short-term events occurring on the background of "normal", autocyclic sedimentation are related to the weather conditions and consequently, such allocyclic event deposits represent very short time intervals — usually lasting between minutes to hours, maximum few days. In continental deposits such event stratification is represented mainly by flood events products — inundites (Seilacher, 1982). Such cycles are characterised by erosional base, sandstone with trough cross bedding lithofacies, fining-upward grading, rippled top with plant roots. Their thickness usually range from several centimetres to about 1 metre. Examples of such "event bedding" come from the Sołtyków section, depth 17.0–20.2 m (Fig. 6). Inundites are usually recognisable only in meandering river floodplain depositional subsystem and they can be often identified with parts of crevasse splay deposits.

In nearshore depositional systems, storms are the most common turbulent events. Sedimentlogically, individual storm beds can be recognised by distinctive erosional features and sequence of sedimentary attributes (Dott, Bourgeois, 1982; Aigner, 1985), and they are called tempestites. An amended scheme of proximal and distal tempestites is presented in Fig. 7. Examples of tempestites are presented in Pl. IV, 7 (distal) and Pls. V, 5; IX, 5 (proximal).

ANIMAL BIOFACIES

Animal body fossil finds described by the previous authors are described in the previous chapter. Some new bivalves found by the present author are shown in Plate I. The new finds comprise both fresh-water bivalves found in the Ia and Ib parasequences (Zagaje Formation) and brackish-marine bivalves found in the Ib–k parasequences and higher sequences. Fresh-water forms are represented mainly by the Unionoidea (Pl. I, 1–3). Brackish-marine bivalve assemblages of the Holy Cross Mts comprise mainly representatives of such orders and families as Veneroida (Cardiniidae, *Cardinia*), Mytiloida (Mytilidae, *Modiolus*), Pterioida (Ostreidae, *Liostrea*), Nuculoida (Nuculidae, *Nuculana*; Ctenodontidae, *Palaeo neilo*), Pholadomyoida (Pholadomyidae, *Homomya*, *Pholadomya*), and bivalves incertae sedis (*Taeniodon na- thorsti* Lundgren) — Pl. I, 4, 5, 7–10. In deltaic depositional system, joint occurrence of bivalves representing both Unionoidea and some non-freshwater forms (Cardiniidae, *Mytyloida*) points to a faunal mixing and considerable adaptive abilities among these bivalve families. Determination of the bivalves was based mainly on Troedsson (1951), Cox (1961), Martinson (1961) and Good (1998).

Presence of foraminifera in Lower Jurassic deposits was confirmed by several authors (see the chapter "Previous works"). Besides the Lower Pliensbachian and some parts of the Lower Toarcian deposits in Pomerania region, which contain fairly diversified, marine foraminiferal assemblages, most of the epicontinental Lower Jurassic deposits of Poland are characterised only by impoverished assemblages of agglutinated foraminifera, including such genera as: *Ammodiscus*, *Saccammina*, *Haplophragmoides*, *Crithionina*, *Ammobaculites* and *Trochammina*. *Ammobaculites* and *Trochammina* were reported for example from very shallow marsh deposits of the Lower Carboniferous deposits in Canada (Tibert, Scott, 1999) and other similar formations (Wall, 1976), although all the mentioned forms can also occur in deeper facies. In lowered pH and brackish conditions, simple agglutinated foraminifera dominate (Walton, 1964; Wall, 1976). Finds of paleoniscid fish (Maślankiewiczowa, 1965; Karaszewski, Kopik, 1970) also confirm brackish-marine conditions (Maślankiewiczowa, 1965; Tibert, Scott, 1999). Generally, marginal-marine, marine-brackish environments are characterised by such faunistic/ecological features as: low diversities, high dominances, large populations and very few marine organisms (Tibert, Scott, 1999). This rule is in concordance with most of the Early Jurassic brackish marine bivalve and foraminiferal assemblages.

Finds of floristic remains (of macroscopic scale) from the Holy Cross Mts region were summarised by Makarewiczówna (1928). More recently, studies on floristic remains have been helpful in interpretation of some palaeoclimatic conditions (Reymanówna, 1991; Wcisło-Luraniec, 1991).

Plant roots are included in the present work into macrofloristic „body fossil" category. They are of great importance for interpretation of palaeoenvironment, cyclicity of sedimentation and identifying the depositional sequence/parasequence boundaries. Plant roots are common in Early Jurassic deposits and they represent a great variety of forms (Pl. II). Plant roots may be preserved either as coalified structures (Pl. II, 1, 4, 6, 8, 9a) or as sediment-filled structures, usually with thin coaly lining on the outer surface (Pl. II, 2, 3, 5, 9b, 10, 11), which reflects diagenetic changes in oxygen conditions — the less oxygen in sediment the higher chance for "coalified form" of preservation. Precipitation of diagenetic pyrite confirms that interpretation (Pls. II, 9a; IV, 3). Another feature is length of plant roots. Long plant roots preserved in sandstone (Pl. II, 7) point to lowered water table and more oxygenated soil, which is usually associated with coarser sediments (the Podzols type of palaeosol — Arndorff, 1993). On the other hand, long roots found below palaeosols in lagoonal/interdistributary mudstones (Fig. 8) may also point towards sedimentation along with the plant growth, and it looks essentially like a "reed swamp" (op. cit.). Short, coalified or pyritized plant roots (Pls. II, 1, 4, 8, 9a; IV, 3) point to a high water table and reducing, often acidic conditions (which is usually associated with more fine-grained sediments and Gleysol type of palaeosol — Arndorff, 1993). Moreover, in such type of palaeosol plant roots may develop large, internal chambers which facilitate gas exchange with the outer environment. Some of the Early Jurassic plant roots show collapse structures, which points to existence of such chambers (Pl. II, 8, 9a). Plant roots developed in thin, horizontal layers may point to increased salinity of the soil (Sarjeant, 1975).

Plant roots document the existence of palaeosol. Palaeosols mark hiatuses in sedimentation and often are associated with tops of shallowing-upward sequences and parasequences. In the levee bank, crevasse splay and other freely drained sandy parent material, Polish Early Jurassic palaeosols seem to represents Podzols, while Gleysols and Histosols were developed in the low relief, poorly drained areas covered with backswamps and marshes (Arndorff, 1993).

The presence of pyrite concretions in the palaeosols or coal seams, which are overlain by brackish, marginal marine sediments (Pls. II, 9a, b; IV, 3), suggests that the pyrite was precipitated due to the introduction of sulphate ions by percolating marine water (Martini, Johnson, 1987; Arndorff, 1993).

In some cases, the whole plants in life position were found (Pl. II, 5, 6). Such situation points to a very rapid deposition.

PALYNOFACIES

Palynofacies is regarded as a certain type of biofacies. The palynofacies concept was based on Combaz (1964), who used that palynofacies to embrace all HF and HCl-proof organic remains in a rock sample. In other words, it represents insoluble part of SOM (sedimentary organic matter). The definition of Powell *et al*. (1990), that palynofacies refers to a distinctive assemblage of palynoclasts (= palynological matter, palynomacerals — PM), whose composition reflects a particular sedimentary environment, was regarded by Batten (1996) as too restricting, but for this study this definition is appropriate. Further definition of palynological matter (PM) follows that of Batten (1996), with some amendments based on Van Bergen and Kerp (1990) and Tyson (1995). Palynological matter (PM) comprises the following elements found in the Early Jurassic:

— palynomorphs (sporomorphs = pollen grain and spore, plus phytoplankton including dinoflagellate cysts and Acritarcha);

— structured organic matter (STOM) herein it means phytoclasts or plant detritus (in the present work zooclasts are included in animal biofacies) comprising wood (black and brown), charcoal and other black phytoclasts, cuticles and other non-cuticular tissues. One should be bear in mind, that it is difficult or impossible to discern the opaque structured phytoclasts from the opaque unstructured organic matter is in the transmitting light studies;

— unstructured (structureless) organic matter (USTOM), including amorphous organic matter (AOM), both of terrestrial derivation (AOMT) — dark and usually opaque, and that of aquatic origin (AOMA) — usually light and translucent.

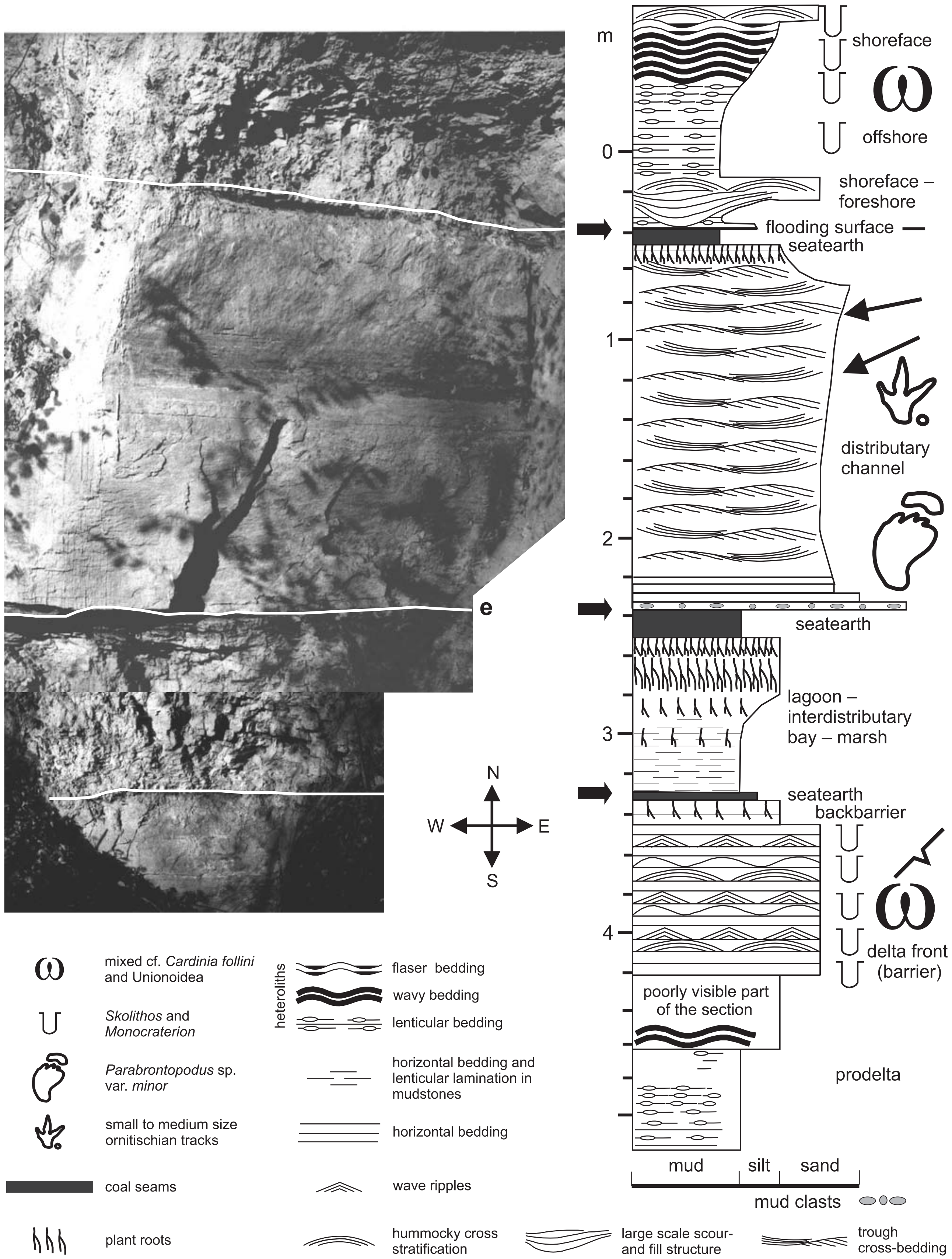


Fig. 8. Profile of the Gromadzice upper exposure showing deltaic and nearshore facies of the depositional sequence I (c and d parasequences, Skłoby Formation)

Note presence of the flanking barrier facies and restricted interdistributary bay/interdeltaic lagoon with very long plant roots at the top, which points to sedimentation going on along with the plant growth. Note that the individual coal/clastics contacts (arrowed) are of different character and rank — only the uppermost one represents the flooding surface (i.e. bounding surface of a regional significance). Formation of this "barren-deltaic sequence" required an equilibrium between wave and fluvial processes; **e** — erosional surface. This section approximately corresponds with the 58.0 – 68.0 m interval in the Miłków-Szewna borehole profile (Fig. 19 CD)

PALYNOMORPHS

Sporomorphs

In the material studied, the sporomorphs are represented by the miospores, conventionally identified with bisaccate pollen and other miospores (spores or precisely microspores). Megaspores are relatively rare and they are insignificant in statistics of palynofacies. Most studies of marine facies show that proximal sediments are comparatively impoverished in bisaccate pollen relative to spores (Muir, 1964). Sporomorphs (particularly miospores) and phytoclasts are strongly correlated with fluvio-deltaic influence (Tyson, 1995). Experiments on *Lycopodium* spores in artificial shallow channels indicate that spore distribution is influenced primarily by water depth and current velocity (Reynolds *et al*., 1990). Tschudy (1969) reported that in Lake Maracaibo larger fern spores are mainly restricted to the vicinities of river mouths. In the Orinoco delta, Muller (1959) found that delta top assemblages are characterised by a marked overrepresentation of sporomorphs produced in the local swamp, but that in the marine realm they were concentrated in belts offshore of the larger delta distributaries (Fig. 9). On the other hand, bissaccate pollens become preferentially concentrated in more fine-grained and deeper water sediments, either of marine or lacustrine origin, due to their high buoyancy and wind transport (Brush, Brush, 1972; Horowitz, 1992). The palynological record is generally strongly biased towards the wind-dispersed bisaccate pollen because of the much larger numbers in which these grains are produced. It is generally estimated that 90 % of pollen grains are finally deposited within 50–100 km of their source (Stanley, 1969). Up to 95 % of all pollen may be deposited initially within 1 km of the parent plant (Traverse, 1988). Assuming all that, the ratio bisaccate pollen/spore is taken in this paper as one of palynofacies indicators, although it must be used with caution. The character of the vegetation can significantly influence the bisaccate pollen/spore ratio and number of all miospores. Spores can concentrate in a great number in "hydrodynamic traps", for example in delta-fringing lagoons (interdistributary bays) or in oxbow lakes on the alluvial plains (Fig. 9). On alluvial or delta plains, the bisaccate pollen/spore ratio is of a lesser significance for interpretation of hydrodynamic conditions, as this ratio depends mainly on the character of local vegetation. For example, in a delta plain — marsh depositional system spores dominate in Gliniany Las 1 borehole (depth 33.0 m, Fig. 5 CD), while bisaccate pollen dominate in a similar setting in Gliniany Las 2 borehole (depth 51.2–51.5 m, Fig. 4). The patterns are brought about because relative proximity of higher lands dominated by coniferous forests increases number of pollen grains in the miospore spectrum. On the other hand, swampy lowlands are characterised by a high water-table and abundance of the spore-producing plants. Generally, sporomorphs are most numerous in delta plain and fringing lagoonal deposits. The highest spore/bisaccate pollen ratios occur near river mouths (distributaries) and locally in delta-fringing lagoons ("hydrodynamic traps"; Fig. 9). Also in high-energy nearshore zones, the spores may be relatively more frequent than bisaccate pollen, because they are more robust than pollen grains and they can be positively selected by turbulent hydrodynamic conditions. In high-energy environments (both fluvial and nearshore), sporomorphs are often mechanically destroyed (Pl. VI, 3). On the other hand, presence of sporangia, including tetrads, point to a very short distance of transport because of their vulnerability to dynamic factors such as currents or waves. Therefore they usually indicate proximity of vegetated areas — except for the case of palynofacies inversion described herein.

Acritarchs and dinoflagellate cysts

Acrirarchs are primarily restricted to shelf environments and they had a meroplanktonic lifestyle similar to that of fossil and modern cyst-forming dinoflagellates (Dufka, 1990). Most studies have consistently demonstrated that a relative abundance of small micrhystridid Acritarcha occurring in the material studied is most characteristic of shallow water marginal marine conditions (Prauss, 1989). This seems to occur mainly in brackish marginal facies. There is no simple relationship between dinoflagellate cyst abundance or diversity and inferred "marinity" of the environment. Generally, they indicate marine or brackish-marine environment. Acritarcha or dinoflagellate cysts — if present — occur in low numbers in the Early Jurassic material from Poland. Thus, they are insignificant as far as concerns quantitative abundance/diversity ratios. However, they are very useful as a general indicator of marine influences and are more frequent in sediments associated with maximum flooding surfaces, where they can be additionally corroded (Pl. VI, 4).

STRUCTURED ORGANIC MATTER (STOM) = PHYTOCLASTS

Coarse phytoclast material (> 1mm) is usually only dominant in high, first and second order, headwater streams (Minshall *et al*., 1985). The amount of organic matter transported by streams and rivers (Pl. VI, 1, 2) is partly a function of discharge of streams and rivers, because the bulk of the terrestrial material is transported during periods of high discharge rate associated with heavy rains. Wood is especially abundant in the vicinity of the delta (Shepard, 1956; Pl. VI, 2). Accumulations of medium to coarse grained plant detritus and recycled coal and lignite debris are apparently common in the swash zone of barrier beaches near the mouths of the Mississippi (Burgess, 1987). The offshore decrease in terrestrial organic matter away from the Mississippi is correlated with a decline in the siliciclastic coarse sediment fraction. The same trend can be observed in Early Jurassic material (Pl. VI). Large and dark angular fragments (Pl. VI, 1) are regarded as oxidized phytoclasts characteristic for high energy, organic-poor facies such as

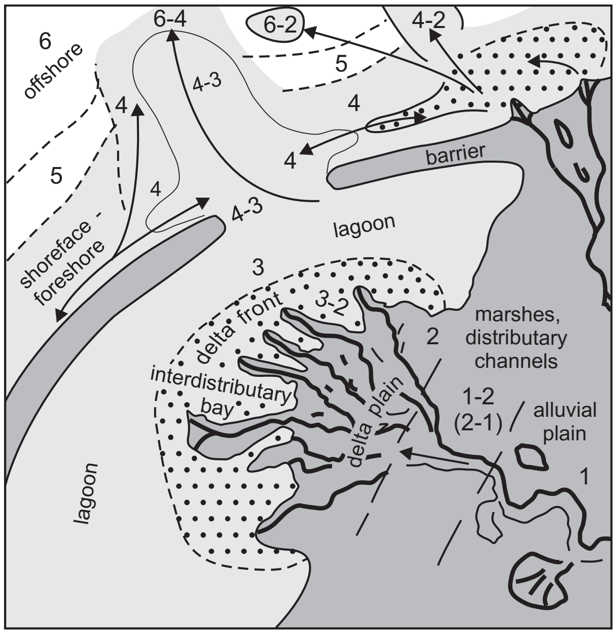


Fig. 9. Palynofacies of the Early Jurassic deposits in Poland and their palaeoenvironmental background (after Pieńkowski, Waksmundzka, 2002)

1 — very abundant palynological matter, varied frequency of sporomorphs, varied bisaccate pollens/spores ratio (depending on a local vegetation), very abundant dark-brown to opaque phytoclasts or AOMT (amorphous organic matter of terrestrial derivation); **2** — abundant dark to opaque phytoclasts (or AOMT) and cuticle, abundant sporomorphs (spores dominate over bisaccate pollens), sporadic presence of dinoflagellate cysts and acritarchs; **3** — abundant sporomorphs, varied bisaccate pollens/spores ratio (usually spores and pollens are in approximate ballance, but sometimes huge number of spores accompanied by tetrads and sporangia occurs in "hydrodynamic traps"), moderate amount of phytoclasts — mostly cuticle, relatively rare dark phytoclasts, rare dinoflagellate cysts and acritarchs; **4** — dispersed and rounded fragments of black, opaque phytoclasts or AOMT, rare to moderate sporomorphs (bisaccate pollens and spores in ballance or slight dominance of spores), sporomorphs often mechanically destroyed, rare dinoflagellate cysts and acritarchs; **5** — rare translucent AOMA (amorphous organic matter of aquatic derivation), very rare small and rounded fragments of opaque phytoclasts or AOMT, rare sporomorphs (bisaccate pollens dominate over spores), occurrence of dinoflagellate cysts and acritarchs; **6** — translucent AOMA, rare bisaccate pollens, spores absent or very rare, occurrence of dinoflagellate cysts and acritarchs

distributary channels, point bars levees and proximal crevasse splays (Scott, Collinson, 1978). Moreover, dark phytoclasts are generally more abundant than translucent brown material in deltaic environment (Williams, 1992).

"Cuticle" (cutin) has been considered to be the most resistant substance produced by plants (Van der Merve, Jootse, 1988). Cuticle (Pl. VI, 2) is most common in deltaic, lagoonal, lacustrine and marsh deposits (Batten, 1973), although a relative abundance of cuticle debris was reported from ancient "oceanic" sediments deposited nearest to active submarine fans (Habib, 1982).

UNSTRUCTURED ORGANIC MATTER (USTOM)

Unstructured (structureless) organic matter (USTOM) is represented in the samples studied only by AOM (amorphous organic matter), which is divided into AOMT (amorphous matter of terrestrial derivation, dark and usually opaque) and AOMA (amorphous organic matter of aquatic origin, usually light and translucent).

AOMT (amorphous matter of terrestrial derivation)

AOMT is represented by dark, opaque fragments being mainly oxidised, transformed fragments of plant tissue (AOMT). The amorphous group (Tyson, 1995) embraces heterogeneous, fluorescent amorphous organic matter, humic gel and resin. Recognition of charcoal is a matter of controversy (Batten, 1996; Tyson, 1995). Relatively small, rounded opaque fragments of AOMT (Pl. VI, 3) can be arguably found in marginal marine and marine facies (Bustin, 1988). It should be pointed out, that in many cases it is difficult or impossible to distinguish between the opaque AOMT and dark, opaque STOM (oxidized phytoclasts) under transmitting light studies. Usually, larger fragments of heavily oxidized STOM may be of a more angular appearance (Pl. VI, 1).

AOMA (amorphous matter of aquatic origin)

It is usually of planktonic/bacterial origin and it shows "spongy", translucent structure (Batten, 1996). It is not determined if it is of plant or animal origin. It is light-brown to pale yellow and white. Translucent AOMA dominate in marine deposits (Tyson, 1995) and it has been found in marine deposits of Pliensbachian age in Pomerania and less frequently in other deposits of marine/brackish-marine origin (Pl. VI, 4).

Palynomorph abundance is generally related to sediment grain size (Tyson, 1995). Therefore, palynological samples described in the present work were taken only from strictly defined lithofacies — mudstones.

Based on unpublished work (Pieńkowski, Waksmundzka, 2002), six palynofacies were proposed for the Early Jurassic deposits in Poland. They are explained in the context of the main depositional systems in Fig. 9. The most characteristic palynofacies are presented in Plate VI.

Important and new in palynofacies studies are palynofacies inversions. The term palynofacies inversion is introduced to explain abnormal composition of palynomacerals. Two types of palynofacies inversions have been recognised (Pieńkowski, Waksmundzka, 2002). The first one represents coexistence in one sample of palynomorphs of the same geological age showing different colour, conventionally identified with TAI (thermal alteration index). It is explained by different burial history of the palynomorphs. Some of them, showing light-yellow colour (typical of the Lower Jurassic material taken from the areas located outside the maximum tectonic burial zones) were settled in the sediment just after their release from the parent plant. Others, showing much darker orange-brownish colours, went through diagenetic cycle in the alluvial plain/delta plain/lagoon swamps and marshes. Subsequently, those darkened palynomorphs were redeposited and included to the sediment. The burial period in swamp/marsh deposits was short enough, however, to consider the palynomorphs as practically contemporaneous, though they show different colours. This type of inversion points to the sedimentary “cannibalism” processes associated both with autocyclic factors (lateral migration of channels, shifting of delta lobes) or allocyclic mechanisms (exceptional floods, storms and changes of sea level). Moreover, such inversion shows that in certain cases colour measurements must be taken with due caution, as they may indicate something else than "conventional"TAI reflecting anepigenetic “tectonic”, burial history.

The second type of palynological inversion is characterised by presence of deltaic/lagoon palynofacies elements in evident open marine deposits. This mixture of different palynofacies elements in one sample is explained by influence of heavy storms, which could introduce marginal-marine palynofacies into an open marine environment. Offshore-directed currents are capable of transporting the sediment far away from shore (Davidson-Arnott, Greenwood, 1976). Moreover, the bulk of terrestrial material is transported during periods of high discharge associated with storms, which is connected with the so-called “wash-out” effect. Offshore — directed currents provide a potential mechanism by which buoyant woody material from continental/marginal marine settings including tetrads and sporangia may be seasonally flushed out and deposited in nearshore or shelf environment (Hedges *et al*., 1988).

Palynological inversions must be taken in account in interpretation of both colour and palynofacies composition. In such cases, the “background” palynofacies elements must be observed when performing correct palaeoenvironmental interpretations.

Enormous number of miospores, concentrated in “hydrodynamic traps” should also be regarded as a local abnormality, but such cases are relatively rare and they have not been distinguished as another type of “palynological inversion”.

Some „micro-scale” fluctuation of palynofacies attributed to seasonal changes have been noted from lacustrine and lagoonal „laminites” (laminated, varve-like mudstone with light-grey and dark-grey lamina — Pl. III, 1).

Palynofacies in the borehole columns are presented as circular diagrams showing the bisaccate pollen/spore ratio and numbers indicating the palynofacies, based on all the other properties, including presence of STOM, AOMT, AOMA (Fig. 9). Presence of sporangia and tetrads, as well as presence of dinoflagellate cysts and Acritarcha, are marked separately. Palynological inversion of second type is also shown separately in the borehole profiles (Fig. 4a — explanations).

ICHNOFACIES

Animal biogenic structures (trace fossils) are important additional descriptive attributes of lithofacies and are divided into basic ethological groups of Seilacher (1967) and Ekdale (1985). Specific assemblages of trace fossils were distinguished (Fig. 10). The assemblages represent the response of animals to number of factors, e.g. substrate, food distribution, oxygenation, salinity and bathymetry. Systematics and distribution of Hettangian–Sinemurian trace fossils in the Holy Cross Mts region in different sedimentary environments (particularly with its relation to the sedimentary cycles) have been presented by Pieńkowski (1985). The present work gives a broadened view — it describes trace fossils assemblages from the open sea sediments and additionally gives a new and more complex description of the continental ichnocoenoses (Fig. 10). Particularly interesting are dinosaur tracks ichnocoenoses (Pieńkowski, Gierliński, 1987; Gierliński, Pieńkowski 1999; Gierliński *et al*., 2001a, b). Inland, a humid to semi-dry environment of alluvial plain with both low- and high-growing vegetation was dominated by high-browsing herbivores (sauropod trackmakers of large *Parabrontopodus*) and large-size predators (allosauroid and ceratozauroid trackmakers of *Megalosauripus* sensu Lockley *et al*., 1996 and *Kayentapus* — Pl. VII, 1, 2, 5, 6). Smaller dinosaur tracks (*Anchizauripus*) also occur. On the other hand, delta plain–barrier/lagoon–marshy environments with low and dense vegetation was invaded by low browsing herbivores such as ornitischian trackmakers of *Anomoepus* and *Moyenisauropus*, and small- to medium-sized predators, such as ornitischian trackmakers of *Grallator* and *Anchizauripus* (Pl. VIII, 1–5). Presence of some small sauropod tracks in this assemblage indicates that small (diminutive

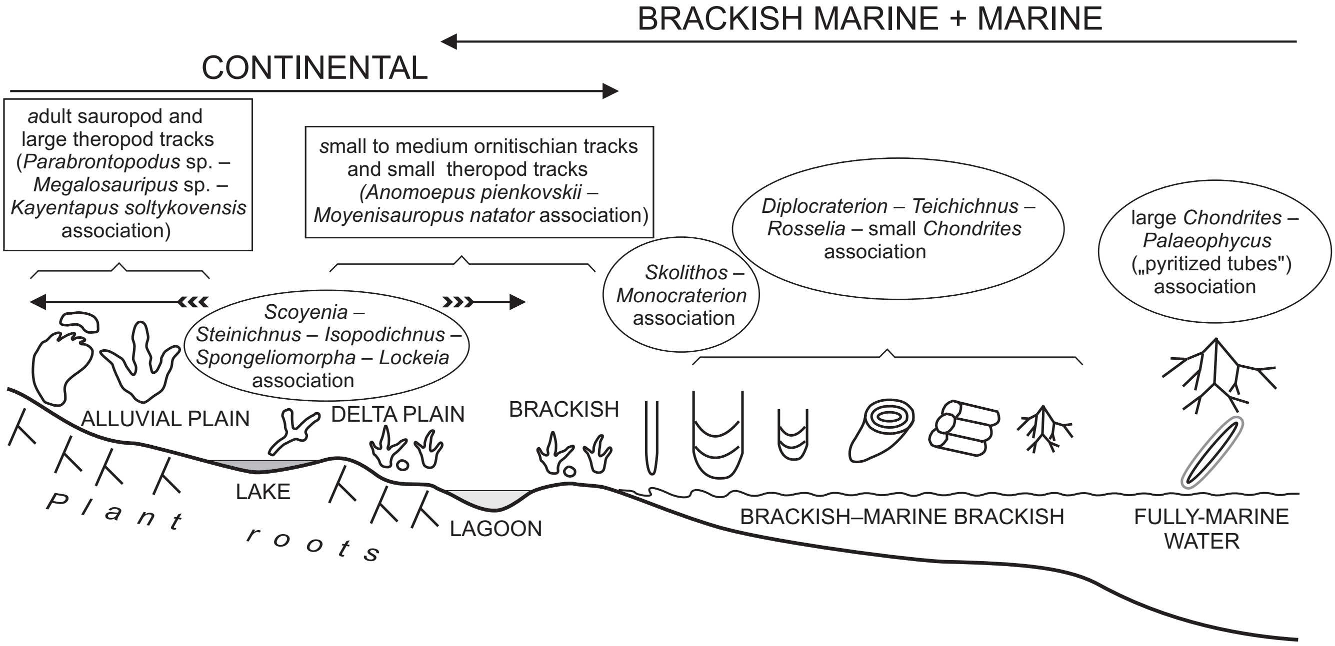


Fig. 10. Trace fossils assemblages from the Early Jurassic deposits in Poland with palaeoenvironmental background

or juvenile) sauropods were low-browsing. Large sauropod tracks are absent from this assemblage. Therefore, two distinct dinosaur tracks assemblages (dinosaur ichnocoenoses) may be distinguished (Fig. 10). The first one (alluvial plain environment) comprise ichnofacies-specific large *Parabrontopodus*, *Megalosauripus* sensu Lockley *et al*., 1996 and *Kayentapus* tracks (Fig. 6). The second one (delta plain–barrier/lagoon environment) is characterised by the lack of large *Parabrontopodus* and *Megalosauripus* sensu Lockley *et al*., 1996 tracks and by the occurrence of *Anomoepus* and *Moyenisauropus* tracks associated with small theropod (*Grallator*) tracks (Figs. 8, 11). Ichnofacies-specific forms seem to be represented by basal thyreoforan footprints: *Anomoepus pienkovskii* Gierliński and *Moyenisauropus natator* Ellenberger (Fig. 11; Pl. VIII, 1, 2). Small sauropod footprints (small *Parabrontopodus*) and *Anchizauripus* footprints seem to represent facies-independent forms (Figs. 6, 8, 10).

Description of invertebrate trace fossils representing continental deposits (Pieńkowski, 1985) needs mendment. *Lockeia* James (= *Pelecypodichnus* Seilacher — the junior synonym) bivalve resting-burrowing traces do occur in fresh-water environment. The density of the *Lockeia* varies enormously, with some slabs showing only the occasional specimen while on others they are very densely packed (Pl. VII, 4 a, b; Fig. 6). Burrowing bivalves can produce a variety of ichnoforms (Pieńkowski, Niedźwiedzki in prep.). Shallow (resting) forms are traditionally named *Lockeia amygdaloides*(Seilacher) and deeper, asymmetrical dwelling burrows are assigned to the ichnospecies *Lockeia czarnockii* (Karaszewski) — Pieńkowski, 1985. In some cases the vertical burrowing structures are up to 20 cm long and they resemble the bivalve burrows described by Thoms and Berg (1985) and Hanken *et al*. (2001). The bivalve-produced structures can be ethologically attributed to the shallow resting tracks (cubichnia) = *Lockeia amygdaloides*(Seilacher), deeper dwelling structures (domichnia) = *Lockeia czarnockii* (Karaszewski), and yet deeper, dwelling-escape burrows (domichnia–fugichnia) = *Conichnus* sp., *Conostichus* sp. (Pl. VII, 4a, b) or *Scalichnus phiale* Hanken, Bromley and Thomson. The deepest/longest structures with menniscate infillings are interpreted as upward escape structures (fugichnia) from anastrophic burial by flood-deposited sediment.

Arthropod-made trails and burrows are the most common ichnofossils in the fresh-water facies. Unbranching *Scoyenia* burrows have been found there (Pl. VII, 3), together with branching forms, assigned to such ichnogenera as *Steinichnus* (Bromley, Asgaard, 1979) and *Spongeliomorpha* (Schlirf, 2000). It is worth mentioning, that the insect body fossils have been found in the Sołtyków exposure (Wegierek, Zherikhin, 1997). Invertebrate burrows are most numerous in sediments deposited in the floodplain/crevasse splay depositional subsystem (Fig. 10). Generally, one can distinguish an aquatic fresh-water association (*Lockeia, Conichnus, Conostichus, Scalichnus, Imbrichnus, Cochlichnus, Isopodichnus* and other forms) and subearial to "wet" association (*Scoyenia, Steinichnus, Isopodichnus, Spongeliomorpha* and other forms) (Pieńkowski, Niedźwiedzki, in prep.).

Brackish-marine trace fossil assemblage is richer and more diversified than non-marine traces (Pieńkowski, 1985; Pls. VIII, 6, 7, 9; IX, 6, 7; Fig. 10). Some new forms have been

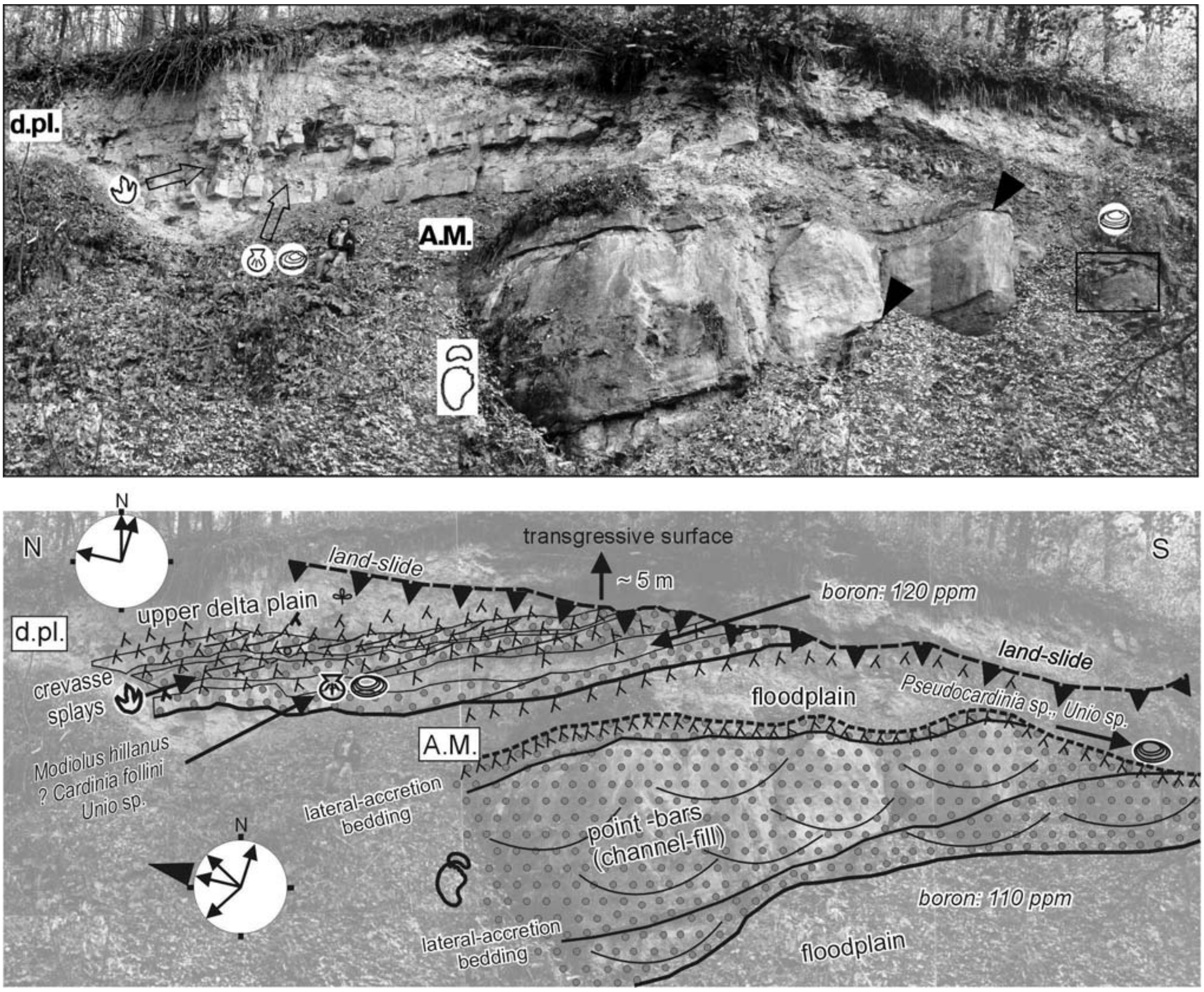


Fig. 11. Mixed meandering-avulsion controlled alluvial depositional system (A.M. — lower part of the exposure) and aggradational, avulsion-controlled delta/alluvial plain depositional subsystem (d.pl. — upper part of the exposure). Lower Gromadzice exposure, Early Hettangian, depositional sequence I b, uppermost Zagaje Formation

Note channelised, lenticular sandstone bodies in the lower part of the exposure (channel-fill subsystem lithofacies with lateral-accretion bedding and plant roots in the uppermost part; dinosaur — sauropod tracks *Parabrontopodus* sp.; Unionacea bivalves such as *Pseudocardinia* sp. — Pl. I, 3 and other forms were found in the dark-grey, organic-rich mudstone floodplain deposits; transport directions generally from SE to NW — sum of vectors). Overlying deposits in the upper part of the exposure (d.pl.) represent laterally persistent sandstone (wackestone) beds of prograding, micro-delta crevasse splays, mudstones are light grey and contain mixed brackish-marine and fresh-water bivalve fauna: *Modiolus hillanus* (Pl. I, 5), ?*Cardinia follini* Ludgren and Unionacea. Numerous dinosaur footprints (marked) represent characteristic assemblage containing smaller forms left by basal ornitishians, such as *Moyenisauropus natator* (Pl. VIII, 2; see also Fig. 10). Transport directions generally from SSE to NNW. Note that the boron content is slightly higher in the upper part of the exposure (120 ppm) than in the lower part (110 ppm). This exposure documents a "transitional" pattern of transgression (alluvial plain/meandering channel deposits passing into the delta plain deposits of aggradational, avulsion-controlled character with brackish water incursions). The transgressive surface occurs 5 metres above this exposure. This section approximately corresponds with the 70.0–75.0 m interval in the nearby Miłków-Szewna borehole (Fig. 19 CD)

described (such as *Scolicia* — Pl. IX, 6). Trace fossils play an important role in differentiating sedimentary environments, because their ethology reflects environmental conditions. Domichnia (dwelling structures), particularly *Skolithos* Haldeman (Pl. VIII, 8), *Monocraterion* Torell (Pl. VIII, 6) and *Arenicolites* Salter (Pl. VIII, 9) are common in foreshores–horeface, high-energy sandy deposits, while deposit feeders (fodinichnia) dominate in offshore settings (Fig. 10). Gradual upward increase in size and density of dwelling burrows indicate both autocyclic or allocyclic shallowing (Pls. VIII, 9; XIV, 7). In shallow-marine, high-energy lithofacies there are also bivalve resting tracks *Lockeia amygdaloides* (Seilacher) and various locomotion trails (Pl. IX, 6). In coarse-grained, delta front deposits of fluvial-dominated, birds-foot deltas domichnia are rare due to large amounts of mineral suspension, which is unfavourable for the suspension feeders (Rhoads, Young, 1970; Pieńkowski, 1985). Escape structures (fugichnia) are common in storm cycles (Pieńkowski, 1985).

The *Diplocraterion* dwelling burrow is of importance as a palaeosalinity indicator (Fig. 10). Taxonomy of *Diplocraterion* ichnogenera was discussed by Fürsich (1974b). Only one ichnospecies — *Diplocraterion parallelum* Torell — has been distinguished in the Early Jurassic deposits of Poland. The trace occurs as either small forms (Pl. IX, 2, 3) or large forms (Pl. IX, 1, 4) in deposits obviously connected with environments of at least brackish to normal or nearly normal salinity. Salinity is indicated independently by biofacies, boron content and palynofacies. Salinity was probably the main factor controlling the size of *Diplocraterion*, bathymetry played a subordinate role (Fig. 10). Otherwise, *Diplocraterion* occurs in a variety of lithofacies — mudstones and lenticular heteroliths (Pl. IX, 1, 2), flaser heteroliths (Pl. IX, 4) and in sandstones. It seems that even short-lasting increase of energy of environment was sufficient for the trace-maker to colonise the muddy bottom. Deep-burrowing habitat was an effective strategy to avoid exposure to the harsh environmental conditions. Joint-occurrence of protrusive and retrusive burrows (Pl. IX, 4) confirms an excellent adaptation of *Diplocraterion* trace-makers to the rapid changes in energy of environment (Goldring, 1962, p. 242). Genesis of the retrusive and protrusive spreite forms of *Diplocraterion* was discussed by Fürsich (1974b). He confirmed the view of Goldring (1962) that such preservation was a response of trace-maker to sedimentation or erosion. Both the retrusive as well as the protrusive spreite (Pl. IX, 4) are therefore an expression of the same behaviour: to keep the deep end of the burrow at an optimum distance from the depositional interface. This is consistent with its interpretation as the dwelling burrow of a suspension-feeder (Fürsich, 1974b). In Early Jurassic deposits in Poland, *Diplocraterion* occurs in a variety of sediments of the nearshore depositional system, from foreshore intertidal zone to shoreface–offshore heteroliths or mudstones, although it seems to be most common in the shoreface–foreshore depositional subsystem, particularly in sediments interpreted as tidal flats. It is worth mentioning, that Olóriz and Rodriguez-Tovar (2000) assigned *Diplocraterion* to the *Cruziana–Skolithos* ichnofacies — distal shoreface to upper offshore (Seilacher, 1967), while Ager and Wallace (1970) and Ahlberg (1990) regarded *Diplocraterion* as characteristic element in intertidal deposits. Fürsich (1974a) regarded *Diplocraterion* as characteristic of a high-energy, *Skolithos* ichnofacies. *Diplocraterion* is characteristic either of transgressive successions or beginning of sea level fall, i.e. the end-HST successions. Dam (1990) interpreted the occurrence of deposits with dense burrows of *Diplocraterion parallelum* Torell and *Diplocraterion habichi* (Lisson) as characteristic of omission at transgressive surfaces. Olóriz and Rodriguez-Tovar (2000) regarded horizons with *Diplocraterion parallelum* Torell as good correlative horizons related to the relative sea level fall and increased energy of environment. Other research also identified *Diplocraterion parallelum* Torell in horizons related to relative sea level rises of different orders (Mason, Christie, 1986; Taylor, Gawthorpe, 1993; Goldring *et al*, 1998). This paper further confirms that *Diplocraterion* is often associated with successions characterised by changes of sea level. In the Lower Jurassic of Poland *Diplocraterion* seems to be a salinity-related form of rather broad bathymetric spectrum (mixed *Skolithos–Cruziana* ichnofacies) — Fig. 10. Pieńkowski (1991a) noted characteristic appearance of *Diplocraterion* in basinward facies with increased salinity — meaning salinity above an oligohaline one. Ahlberg (1990) and Taylor and Gawthorpe (1993) related *Diplocraterion* to marine flooding surfaces reflecting short-lived marine incursions in Mesozoic deposits. The present work fully confirms conclusion of Olóriz and Rodriguez-Tovar (2000) that *Diplocraterion parallelum* Torell is an unique component with respect to relative sea level change and it may be an indicator of both transgressive or regressive pulses. Bromley and Uchman (2003) claimed that *Diplocraterion* is chiefly related to a tidal flat environment characterised by lowered salinity. According to these authors it can be also associated with very shallow pools on a tidal flat. Nevertheless, *Diplocraterion parallelum* Torell in Lower Jurassic of Poland is usually associated with at least mid-mesohaline to polyhaline conditions. Moreover, it is practically absent from deltaic environment (except for deltas strongly reworked by wave processes), which points that there was a certain salinity treshold (probably mid-mesohaline conditions) that allowed occurrence of *Diplocraterion parallelum* Torell.

Recurrent colonisation by *Skolithos* may appear in upper parts of storm cycles — tempestites (Fig. 7), reflecting local and periodical elevation of energy of environment against the "background" *Cruziana* ichnofacies reflecting lower depositional energy (Pl. IX, 5). Storms not only affect the background infaunal deposit feeders and their preservation, but commonly create different bottom conditions with different suspension feeders. These allow the short-term establishment of a different post-event ichnofauna (Seilacher, 1981; Aigner, 1985).

Another dwelling burrow occurring in *Cruziana* ichnofacies is *Rosselia* (Pl. IX, 8a, b). Other ichnogenera of the Cruziana ichnofacies comprise feeding burrows (fodinichnia), such as *Spongeliomorpha* (Pl. IX, 5), *Teichichnus* (Pl. X, 1a, b), *Chondrites* (Pl. X, 2, 3, 5), *Tuberculichnus* (Pl. X, 4) and most common form, *Planolites* (Pl. X, 8). It should be noted, that all forms previously named *Ophiomorpha* have been revised and synonymised as *Spongeliomorpha* (Fürsich, 1973; Schlirf, 2000). Also resting tracks of bivalves — *Lockeia amygdaloides* (Seilacher) (Pl. IX, 7) — and various locomotion trails (Pieńkowski, 1985) are common. Escape structures (fugichnia) occur in tempestites (Pieńkowski, 1985). *Cruziana* ichnofacies is by far the most diversified — both in terms of ichnofabric density and number of ichnotaxa. The most characteristic ichnotaxa are used in the present work to define this association (Fig. 10): small and large dwelling structures (domichnia): *Diplocraterion parallelum* and *Rosselia*, and feeding burrows (fodinichnia): *Teichichnus*, and small *Chondrites*. Dense colonisation of *Rosselia socialis* was described by Nara (2002) from the Pleistocene inner shelf deposits. This colonisation was connected with a transgessive systems tract, when increased rate of deposition prevented colonisation by most benthic animals. In the Lower Jurassic deposits of Poland, *Rosselia* sp. is connected also with transgressive systems tract and occurs near maximum flooding surface within offshore marine sediments of the depositional sequence V (Early Pliensbachian, *davoei* Zone) in the Pomerania region.

Deep marine, grey mudstone lithofacies, for long periods of time deposited below storm-weather wave base, occur only in the west part of Pomerania region in the Pliensbachian. Trace fossil associations in this offshore depositional subsystem are characteristic, containing mainly larger tiers of *Chondrites* and "pyritized tubes" — representing lined *Palaeophycus tubularis* Hall burrows as well as the burrows *Helminthopsis* and *Planolites* (Pl. X, 3, 6–8; Fig. 10). Dwelling burrows (domichnia) are very rare or absent from this association. *Palaeophycus* is strictly defined by its lining (Pl. X, 3, 6, 7) and is commonly interpreted as an open burrow produced probably by polychaetes, filled generally with the same sediment as the host sediment (Schlirf, 2000). Sometimes concentrations of shell fragments within the burrow (Pl. X, 6) are also found. It is not clear if the trace-making organism was swallowing the sediment, leaving behind digested matter enriched in small bivalve shell fragments or it was actively feeding on them. Assuming low-energy conditions below storm-weather wave base, which was the dominant condition, action of a predatory animals would be the most probable explanation of such infillings of some *Palaeophycus* burrows.

Chondrites is represented by smaller and larger forms. The suite is dominated by larger forms representing a shallower tier than the smaller form (Bromley, Ekdale, 1984). *Chondrites* is juxtaposed on shallower *Palaeophycus* (Pl. X, 3). Shallow forms are represented also by *Planolites* and *Helminthopsis* (Pl. X, 8). Despite apparent tiering, trace fossils in these deposits are not diverse, probably owing to ephemeral oxygen-deficient conditions at or beneath the sea floor. Many forms are pyritized (Pl. X, 7, 8). *Chondrites* occurs in all types of sediment, including those deposited under anaerobic conditions. Sometimes, *Chondrites* occurs in black, laminated, carbonaceous sediment that was deposited during chemically reducing conditions (Brenner, Seilacher, 1978; Bromley, Ekdale, 1984). Thus, the presence of *Chondrites* in a deposit indicates very low oxygen levels in the interstitial waters. Oxygen-poor conditions influence the distribution of *Chondrites*-making organisms to a much more significant degree than do bathymetry or sediment type (Bromley, Ekdale, 1984).

CHEMOFACIES

Further information has come from analysis of boron content in mudstones. It is known that boron concentrations are generally higher in marine deposits than in fresh-water deposits (Degens *et al*., 1957; Harder, 1961; Stewart, Parker, 1979). Only boron content in illite is a reliable indicator of palaeosalinity, as boron is chiefly concentrated in illite and once absorbed in this clay mineral, becomes rather stable (Harder, 1961). Therefore, in every sample also the content of K_2O must be indicated, as it is proportional to the content of illite. All the samples were calculated according to the following formula: content of boron in illite = content of boron in a raw sample × 8.5/content of K_2O.

Generally, boron should be also examined in separated samples (fraction < 2μm), and about 50% of the samples went through this procedure. However, comparison of results obtained from 102 samples from five boreholes, in which boron content was measured both in raw mudstone samples and in the fraction < 2μm from the same samples, shows Pearsonian correlation coefficient between 0.5 to 0.8 in respective boreholes, thus pointing to moderate/high correspondence of the results obtained from raw and separated samples. It means that the measurements taken from the raw samples are also reliable — provided that they are carefully taken only from mudstones.

It should be emphasized that in the present work determination of boron content was performed using one method — spectrography, but first analyses were performed some 20 years ago. Different equipment and different chemical patterns were used, although not within samples from the same borehole. It means that one can compare the relative boron content in a given borehole (more boron–less boron), but absolute boron content in ppm must be treated as a crude estimation. However, what is really important is the relative boron content. It should be also mentioned, that the same amount of boron in rocks of different ages reflects different environments (Ernst, 1970).

Generally, boron content points to palaeosalinity, but this indicator must be treated with caution. It is known, that also organic matter can concentrate boron (Walijew, 1977; Uličny, 1989). Due to that, Uličny (1989) rejected boron content as a palaeosalinity indicator, but his samples from Cenomanian of Bohemia were composed mainly of kaolinite and represented varied lithologies, so they were rather not suitable for such analyses. Another problem is, that boron content may depend on its content in a sediment-source area (Spears, 1965). Indeed, such situation seems to occur in some samples taken from the lowermost part of the Lower Jurassic deposits in the Holy Cross Mts (lowermost Zagaje Formation). Underlying Triassic deposits contain high amounts of boron. Subsequent earliest Hettangian erosion could derive boron-rich sediments to the earliest Hettangian deposits, causing abnormally high boron content in these rocks. The other problem is associated with lagoon–barrier depositional system. It seems that in such environments the boron content is very unstable and can vary rapidly in the profile (see Gliniany Las 1 profile — depth between 10.0 and 35.0 m, Fig. 5 CD). The variability can be explained in two ways: concentration of boron in palaeosols (marshes) or local evaporation, which can substantially increase the boron content. Despite such irregularities, boron content can be used as a general palaeosalinity indicator, provided that it is not the single indicator. Moreover, each basin has its own conditions of boron distribution, reflected in the overall concentration of boron in the deposits.

Clay minerals of the Early Jurassic deposits in Poland are represented mostly by illite and kaolinite (Maliszewska, 1967, 1997). It is now widely accepted, that clay mineral assemblages do not simply relate to distance from shoreline (Meade, 1972; Edzwald, O'Melia, 1975), instead registering predominantly changes in source area, climate and topography and sediment transport mechanism, or authigenetic and diagenetic development of clay minerals after deposition (Bonorino, 1966; Wilson, 1972; Deconinck, Vanderaveroet, 1996; Hesselbo, 1996; Deconinck *et al*., 2003).

Higher content of magnesium in sideritic clays and presence of sideroplesite may possibly point to increased palaeosalinity

(Wyrwicki, 1966; Pieńkowski, 1980), as higher content of magnesium is usually associated with marine waters (Müller, 1964; Makiedonow, 1977).

It is generally accepted that a high pyrite content in a palaeosols and coaly facies suggests marine influence (Postma, 1982). In the Early Jurassic deposits of Poland, pyrite-bearing palaeosols and coals often underlie flooding and transgressive surfaces (Pls. II, 9a, b; IV, 3). The same rule related to diagenesis of coal was shown by Ketzer *et al*. (2003). Moreover, dolomite/calcite cementation often occurs above or at the parasequence boundaries (flooding surfaces), particularly in Pomerania region and in the Fore-Sudetic Monocline. Sometimes this cementation is also associated with subordinate sedimentary cycles, usually at the top of submerged barrier facies. It is consistent with Ketzer *et al*., 2003 (their stratabound calcite/dolomite cementation).

Occurrence of chamosite in Early Jurassic deposits in Poland (Maliszewska,1967, 1997) is restricted to marine and brackish-marine deposits. Chamosite ooids are sometimes associated with parasequence boundaries (flooding surfaces) in the Pomerania–Fore-Sudetic Monocline area. However, this mineral cannot be regarded as an indicator of marine conditions: chamosite or its precursor berthierine is known to occur also in terrestrial settings (Sheldon, Retallack, 2002).

It should be pointed out that in this paper chemofacies (boron content, clay minerals and magnesium content) were applied only as additional palaeosalinity indicators and no interpretation was made based only on these indicators.

DEPOSITIONAL SYSTEMS AND SUBSYSTEMS

The concept of the term “depositional system” is based on principles summarised by Galloway and Hobday (1996). According to the authors, the depositional basin defines the boundaries and general conditions of the accumulation of a sediment pile. The depositional systems provide “meaningful sections” of the basin fill. The approach to depositional system interpretation used in the present work emphasises the process-oriented, palaeogeomorpological elements that formed a palaeolandscape and the particularly important attribute of palaeosalinity. The present work follows definition of a depositional system given by Galloway and Hobday (1996), based also on the original application of Fisher and McGowen (1967). This definition says: “a depositional system is a contiguous suite of process-related sedimentary environments”. Abandoned systems are buried and become three-dimensional rock bodies with defined areal extent and stratigraphic thickness. Differing depositional environments and systems are characterised by the interplay of specific processes, resulting, in turn, in diagnostic erosional and depositional features. An active depositional system consists of a family of related environments, in the present work classified as depositional subsystems. Each environment (subsystem) is represented by a specific genetic facies consisting of one or more lithofacies. Interpretation of individual genetic facies and lithofacies (depositional subsystems) is most effectively accomplished within a depositional system framework. Galloway and Hobday (1996) distinguished eight primary generic terrigenous clastic depositional systems: alluvial fan, fluvial, delta, shore-zone, shelf, slope and base-of-slope, eolian, and lacustrine. In the present work, slope and base-of-slope depositional system do not occur. Eolian depositional system plays a very subordinate role and it was included within the nearshore (foreshore, backshore) depositional system. The shore-zone system in Early Jurassic deposits of Poland is very complex, comprising both nearshore and barrier-lagoon systems. Nine depositional systems with depositional subsystems have been distinguished: alluvial fans, braided rivers with floodplains, meandering rivers and anastomosing rivers with floodplains, lacustrine, delta (fluvial-dominated and intermediate fluvial- and wave-dominated),barrier-lagoon, nearshore and open brackish-marine shelf basin, marine shelf basin, tide-influenced shore zone. All the depositional systems with subordinate subsystems are enlisted in Fig. 4a (column 11)

In distinguishing lithofacies, biofacies, ichnofacies, chemofacies, as well as depositional sequences, one of the most important factors was palaeosalinity. This feature was particularly changing in Early Jurassic epicontinental deposits of Poland. Also circulation in the basin was important for generation of specific lithofacies. Therefore, an “expanded” depositional systems and subsystems classification within the shore zone and shelf zone was necessary. The classification embraces such depositional subsystems as open-marine shelf, open brackish-marine shelf basin, open embayment, embayment and semi-closed lagoon.

This classification was uniformly applied in both exposure and borehole description (Figs. 4, 5, 6, 8, 11). The most common depositional systems and subsystems are presented on the background of modern sedimentary environments, which are good counterparts for the Early Jurassic depositional systems: they are summarised in Figs. 12 (alluvial-meandering river and lacustrine systems), 13, 14 (delta depositional system and its different depositional subsystems) and 15 (nearshore and barrier-lagoon depositional systems). Construction of regional depositional systems/sequences cross sections and palaeogeographical maps needed some simplifications.

Identification of epicontinental Early Jurassic depositional systems and subsystems in Poland is based on the exposures and fully cored boreholes from the Holy Cross Mts region. Exposures provide sufficient data in both vertical and horizontal dimension, which is of fundamental significance for sedimentological interpretation. Only alluvial fan and tide-infuenced shore zone depositional systems were recognised solely in borehole sections (in the latter case from Wielkopolska region — Pobiedziska IGH 1 borehole).

Data from fully cored boreholes were useful in tracing regional changes of depositional systems, sedimentary cycles and parasequences in space and time (Fig. 16). Moreover, comparison between exposures and boreholes from the Holy Cross Mts region allowed extension of interpretation from the exposures to the corresponding parts of boreholes (Sołtyków exposure and Sołtyków Sł-2 borehole, depth 5.0–21.0 m — Fig. 6; Podole exposure — Fig. 17 and Podole OS-3 borehole, depth 58.0–75.0 m — Fig. 18 CD; Gromadzice exposures and Miłków-Szewna borehole, depth 58.0–75.0 m — Figs. 8, 11, 19 CD).

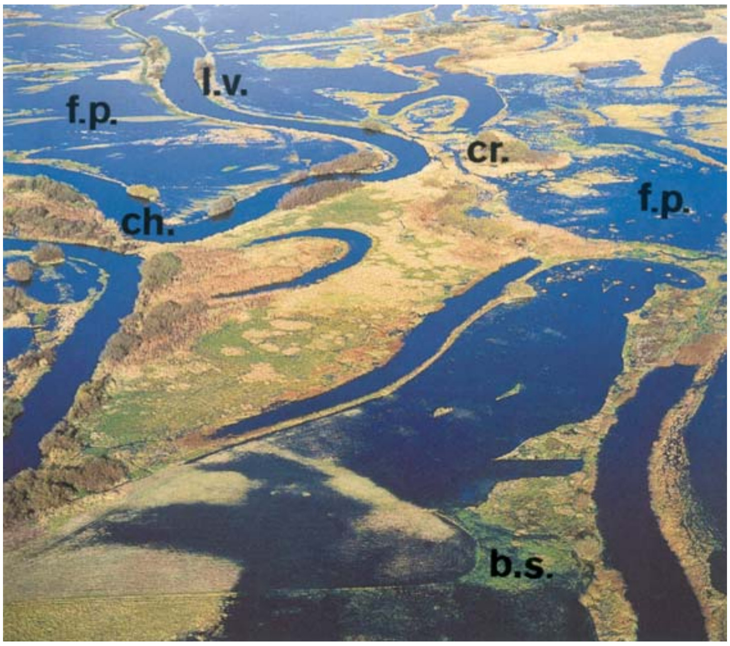


Fig. 12. Alluvial plain depositional system and subsystems of recent anastomosing/high sinuosity Biebrza River (north-eastern Poland) during flood

Photo: Wołkow(WSiP) — modified.

This depositional system has been taken as a good analogue for the Early Jurassic alluvial plain depositional subsystems: **ch.** — channel subsystem; **l.v.** — levees; **cr.** — crevasse splay; **f.p.** — floodplain; **b.s.** — backswamp

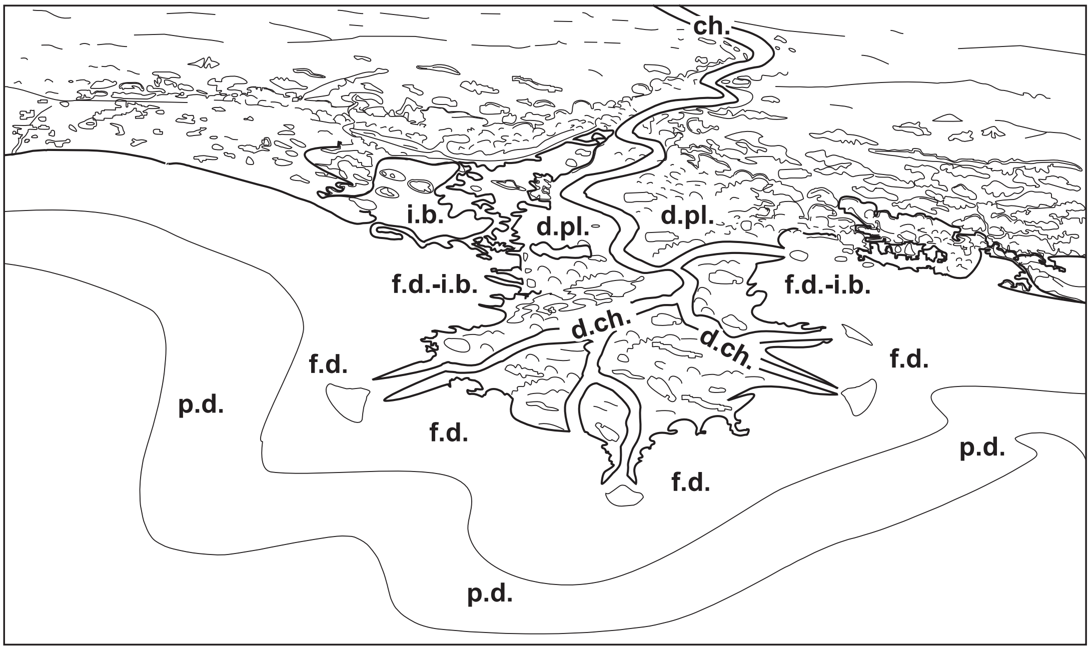


Fig. 13. Birds-foot delta depositional system and subsystems adopted in this work; this fluvial-dominated delta is weakly transformed by wave processes

Abbreviations are explained in Fig. 4a

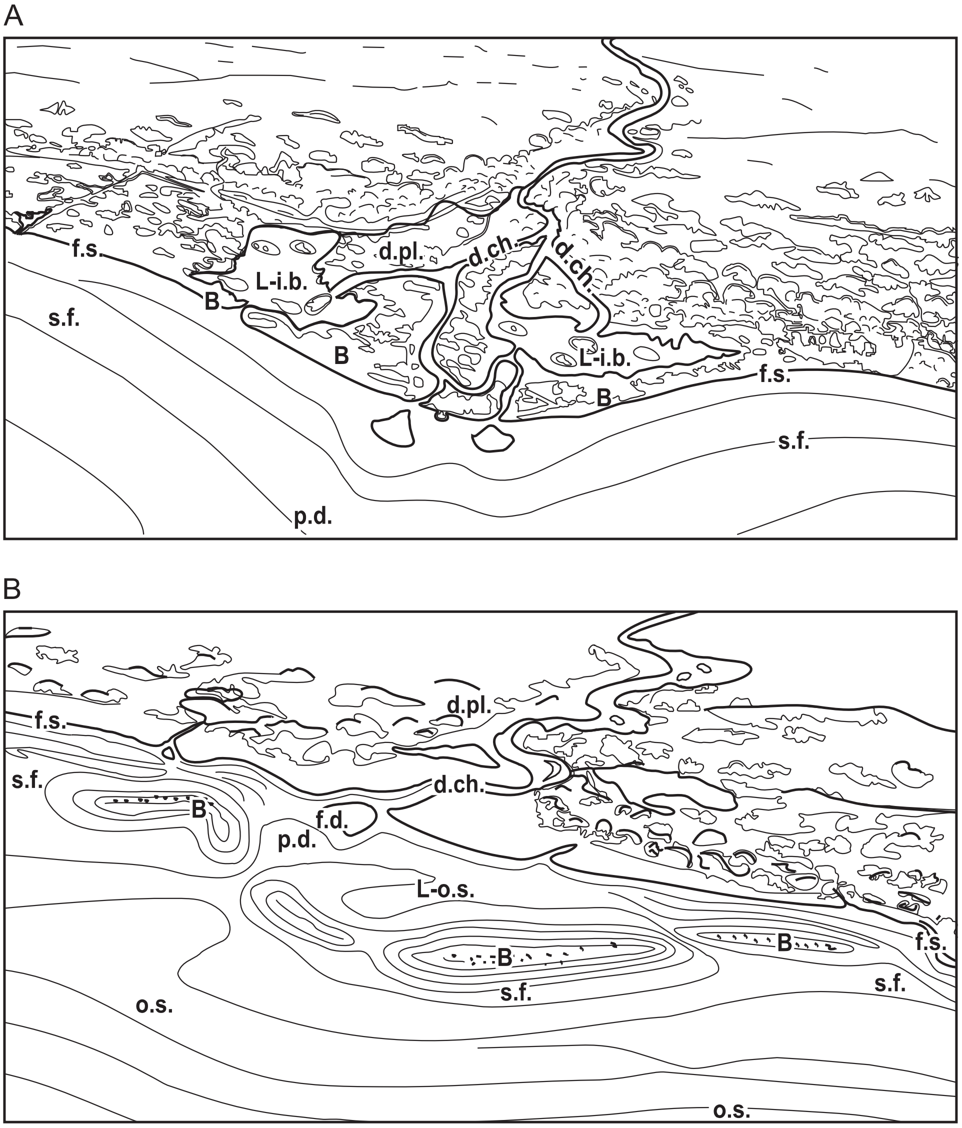


Fig. 14. Reconstruction of the Gromadzice delta system (Fig. 8), showing the barren-deltaic sequence in two stages — progradation of the delta (A) and sea flooding stage (B)

Fluctuations of the local sea-level, caused by number of factors (changes in discharge rate, local sediment budget, local tectonics/subsidence rate, eustacy) are reflected in characteristic cyclicity of the deltaic deposits. Formation of this "barren-deltaic" environment required an equilibrium between wave and fluvial processes. Abbreviations of depositional subsystems are explained in the Fig. 4a

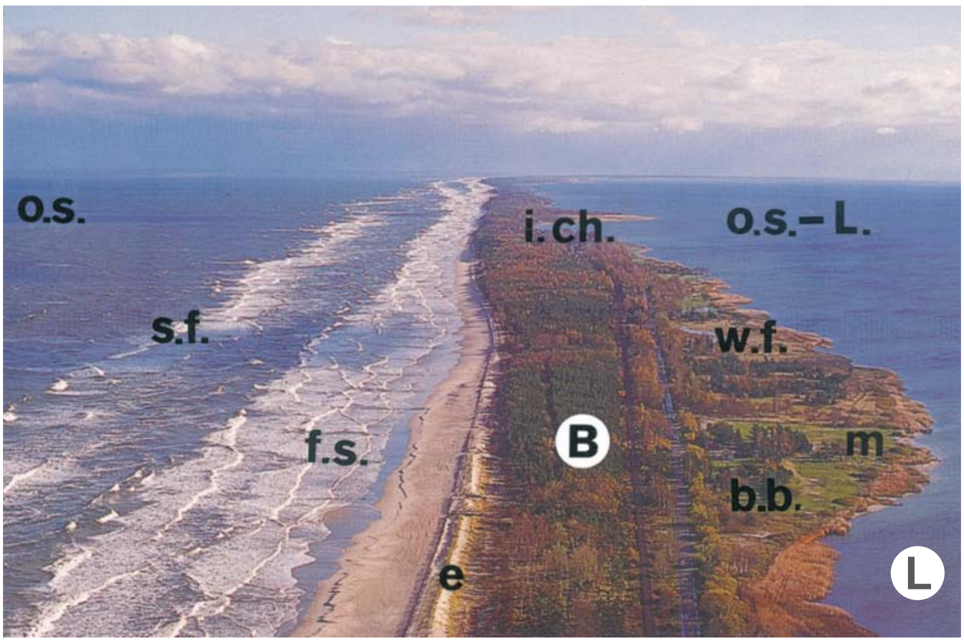


Fig. 15. Nearshore and barrier-lagoon depositional systems and subsystems presented on the background of the Hel Penninsula (Baltic Sea coast, northern Poland)

Photo: Grabowiecki (ARW PAN Dragon Gdańsk) modified

Recent Baltic Sea — Hel–Puck Bay depositional systems has been taken as a good analogue for the Early Jurassic nearshore–barrier/lagoon depositional systems. Abbreviations: nearshore depositional system: **o.s.** — offshore; **s.f.** — shoreface; **f.s.** — foreshore; barrier-lagoon depositional system: **e** — eolian dunes; **B** — barrier core; **b.b.** — backbarrier; **i.ch.** — inlet channel; **w.f.** — washover fan; **m** — marshes; **L** — lagoon; **o.s.-L.** — embayment — transition between lagoon and open sea

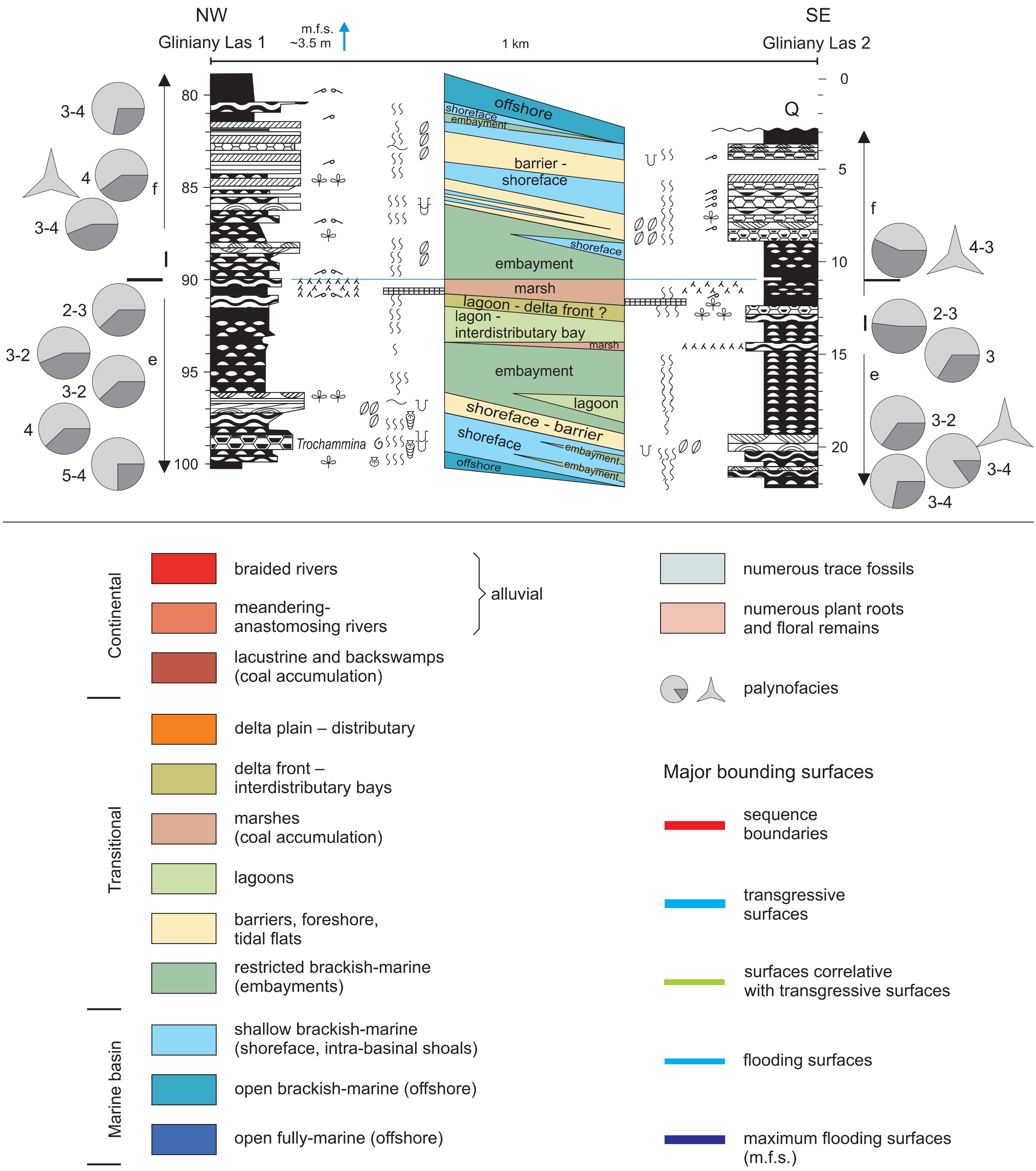


Fig. 16. Cross-section between selected intervals from the Gliniany Las 1 and Gliniany Las 2 borehole profiles (Figs. 5 CD and 4, depositional sequence I e–f, Early Hettangian)

Note the lateral changes of lithofacies, palynofacies and depositional systems/subsystems at a distance of 1 km. There is a general continuity of depositional systems, subsystems and local cycles at that distance, although some lateral facies changes are visible. Blue horizontal line = reference horizon = boundary between parasequence "e" and "f" (correlative flooding sufrace). Note a gradual development of transgression above the flooding surface, which produces more complex facies architecture of marginal-marine parasequences. The legend explaining depositional systems is applicable for other regional cross sections and maps

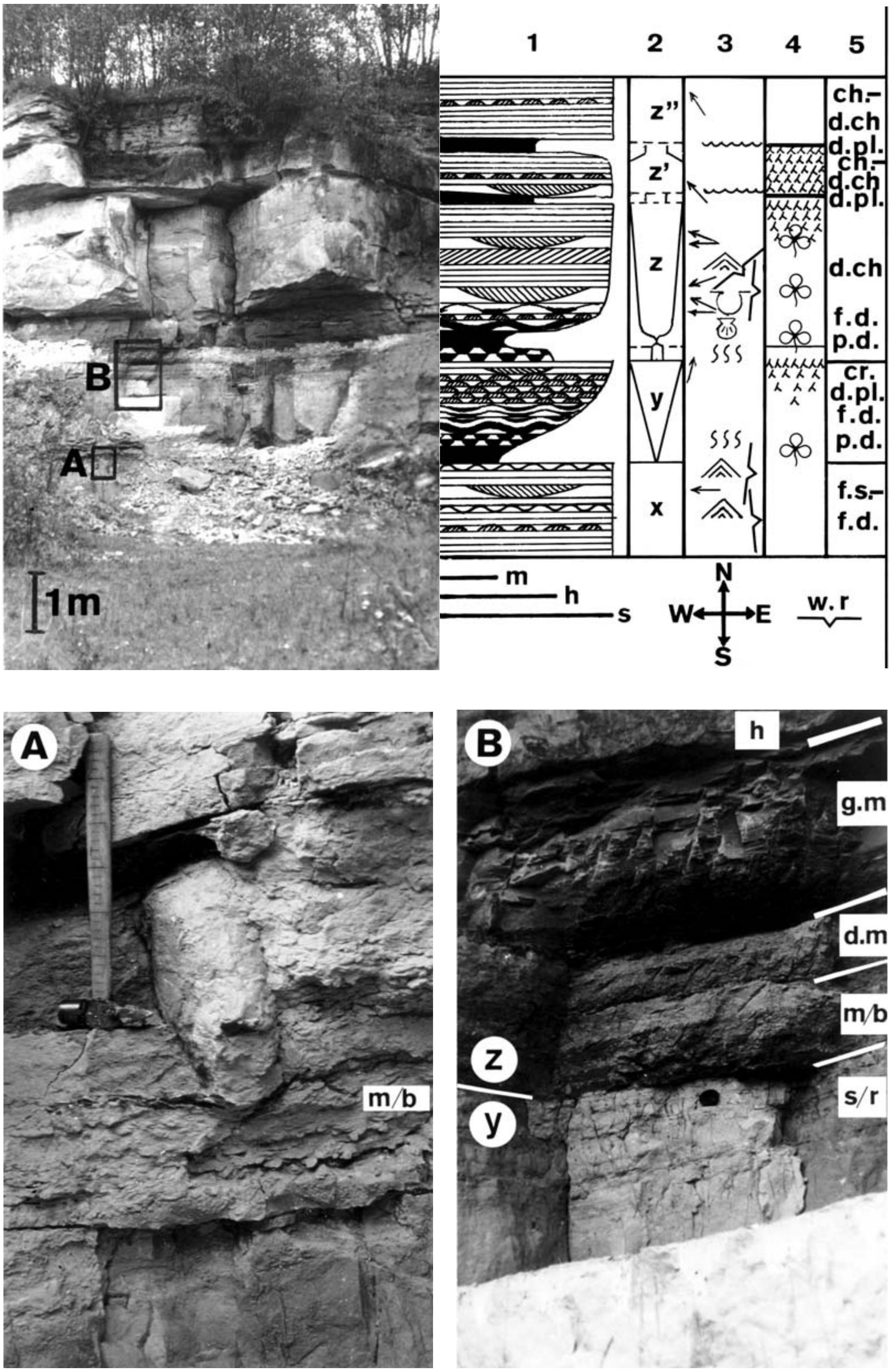


Fig. 17. Profile of the Podole outcrop (Early-Middle Hettangian, depositional sequence I d–e, Skłoby Formation), showing lithofacies and cyclic sedimentation of the delta depositional system (the birds-foot type of delta — see Fig. 13)

Note gradually coarsening-upward sedimentary cycles x, y, z', z''. Column 1 — lithofacies: m — mudstone, h — heteroliths, s — sandstones; 2 — sedimentary cycles with changes of average grain size; 3 — small scale sedimentary structures trace fossils, erosional surfaces, w.r — wave ripple azimuths directions reflecting local alingment of shoreline, arrows - sediment transport directions; 4 — drifted plant fossils, plant roots and coal seams indicating palaeosols; 5 — interpretation of depositional systems and subsystems (for explanation see Fig. 13). **A** — detailed view ("A" frame) showing delta front/foreshore sandstones topping the "x" cycle and overlying bioturbated mudstones (m/b) of the basal prodelta deposits ("y" cycle); **B** — detailed view ("B" frame) showing the boundary between cycles "y" and "z" — the cycle "y" is topped by crevasse-delta plain sandstones with plant roots (s/r). Cycle "z" commences with bioturbated prodelta mudstones (m/b), overlain by the dark-grey, organic-rich mudstones with abundant plant detritus (d.m) and grey mudstones (g.m) of prodelta/delta front transitional facies, covered by heteroliths (h) of delta front facies. The exposure approximately corresponds with the 58.0–75.0 m interval of the Podole OS-3 borehole (Fig. 18 CD)

ALLUVIAL DEPOSITIONAL SYSTEMS

Using term “alluvial”, not “fluvial” needs some explanation. Latin “flumen” or “fluvius” means current, stream or river, so it refers to water running in a river channel. The word “alluvio” means sediment (“earth”) deposited by river, it means also flood. Assuming the fact that not all deposits associated with rivers are deposited in channels — substantial deposition occurs actually in floodplains — it seems that the term “alluvial” is more appropriate, as it embraces in one word both channel and floodplain deposits. Nevertheless, term “alluvial” used in this paper is regarded as synonym of more popular name “fluvial”. In classification adopted in this paper, three alluvial depositional systems were distinguished: alluvial fan depositional system, braided river depositional system (= bed-load, low sinuosity alluvial system) and meandering river depositional system (mixed load–suspended load, high sinuosity to anastomosing/avulsion alluvial system). It should be noted that Miall (1977) distinguished four principal types of river, recognisable on the basis of plan-view morphology: braided, meandering, straight and anastomosing. The types of river are controlled by such chief factors as: water discharge, sediment load, channel slope and type of vegetation. Distinction of a separate depositional system of anastomosing river was regarded as inadvisable for the Early Jurassic alluvial deposits in Poland. Anastomosing/avulsion patterns of interconnected network of low-sinuosity channels occur where contemporaneous branches of a single river weave around permanent, commonly vegetated islands or disconnected segments of floodplain. Anastomosing/avulsion patterns are most common on extremely low-gradient alluvial plains, where stream power is low and banks consist of muddy, cohesive sediment or are highly vegetated (Nanson, Croke, 1992; Emery, Myers, 1996). The present work shows, that the anastomosing/avulsion pattern can be associated with meandering channel alluvial system and mixed patterns of sinuous channel/avulsion sedimentation style can occur (see discussion below). Moreover, “meandering regime” and “anastomosing regime” can appear in one floodplain basin within very short — from geological point of view — time intervals of a mere 5000 years (Aslan, Autin, 1999). Identification of alluvial plains dominated by highly sinuous, laterally migrating channels or anastomosing/avulsion processes must be based on either large exposed areas or 3-D, high-resolution seismic studies. Larger outcrops represent only the Early Hettangian deposits (Figs. 6, 11; Pls. XI, 4–6; XII, 1) and they show a prominent share of anastomosing/avulsion processes, although some features typical of meandering rivers are also present (Fig. 11; Pl. XI, 5). Therefore, a general “meandering and anastomosing river depositional system” has been distinguished and it comprises both alluvial systems: with dominance of lateral channel migration and anastomosing/avulsion processes (Fig. 6; Pl. XI, 4, 6). Such an approach is more appropriate for the material studied and it largely follows the classification of Ouchi (1985), where fluvial deposits were subdivided into bedload braided river system and two meandering river systems: mixed load and suspended load. The anastomosing pattern was thus merged with the meandering river system, as transitions between meandering and anastomosing patterns are typical. Such “mixed pattern” is well visible in the recent Biebrza valley in eastern Poland (Fig. 12). This pattern with intensive crevassing and avulsion processes on one hand, and presence of high-sinuosity, laterally migrating channels leaving oxbow lakes behind on the other hand, is particularly useful for the alluvial depositional systems in the Early Jurassic deposits of Poland.

Apart from the system- and subsystem-specific lithofacies discussed further in this chapter, other types of facies representing the alluvial depositional systems are characterised by :

— dominance of characteristic fining-upward cycles (Allen, 1964b; Cant, Walker, 1976);

— abundant plant roots, plant remains and coal intercalations;

— palynofacies with very rich palynomacerals dominated by large fragments of phytoclasts, and numerous sporomorphs (Pl. VI, 1);

— characteristic biofacies of fresh-water bivalves (Pl. I, 1–3) and other fossils such as insects (Wegierek, Zherikin, 1997);

— non-marine ichnofacies containing characteristic arthropod burrows and bivalve burrows; dinosaur footprints are particularly characteristic, typical (facies-specific forms) include large *Parabrontopodus* (sauropod tracks) and large theropod tracks (*Megalosauripus* sensu Lockley *et al*., 1996 and *Kayentapus*) — Figs. 6, 10; Pl. VII;

— generally, low boron content.

ALLUVIAL FAN DEPOSITIONAL SYSTEM

Alluvial fan deposits occur only in a few places in proximal parts of the earliest Jurassic basin. This depositional system is distinguished only in the Podole OS-3 borehole (depth 82.0–83.5 m — Fig. 18 CD) and from the Miłków-Szewna borehole profile (depth 120.0–123.0 m — Fig. 19 CD). Presence of this depositional system, forming aggradational coarse clastic wedge, is associated with the synsedimentary fault (Fig. 20) running between these boreholes and active during Earliest Hettangian times. The lack of sufficient data does not allow confirmation of the presence of similar alluvial fan systems along other active faults, particularly the Nowe Miasto–Iłża Fault (Figs. 1, 20). This depositional system was distinguished on the basis of presence of characteristic massive gravel-sand lithofacies, is represented by deposits of gravely-sandy braided channels with perennial flow (stream flow fan facies). Plant roots and trace fossils were not found in deposits representing this system, due to unfavourable living conditions and low preservational potential.

ALLUVIAL — BRAIDED RIVER DEPOSITIONAL SYSTEM

Characteristics of the Early Jurassic, the braided river depositional system is based on number of exposures from the Szkucin–Lipa area near Przedbórz (Fig. 20; Pl. XI, 1, 2, 3), representing the lowermost part of the Zagaje Formation (Pieńkowski, 1980). Coarse-grained lithofacies (conglomerates) prevail in the lowermost part of the section (Pl. XI, 1). Conglomerates show horizontal and trough-cross bedding sets of large scale. They represent low-sinuosity braid channel-fill deposits. Higher up in the section sediment is more fine-grained and trough- and tabular cross-bedded, sand and sand-gravel lithofacies dominate (Pl. XI, 2, 3). Conspicuous trough- and tabular cross bedding sets point to deposition mainly in longitudinal bars and transverse bars. In longitudinal bars and channel-fill deposits, sand-gravel, trough cross-bedded conglomerates dominate. In transverse bars, sediment moved down the lee side at flood's peak producing foresets of low-to moderate angle, tabular or tangential cross bedding sets. Characteristic lateral bars occurred at the slopes of large longitudinal bars (Pl. XI, 3). They were formed during a waning high-discharge period, with depositional directions perpendicular to the mean channel flow direction (Rust, 1972). Channel-fill is the only depositional subsystem distinguished within this depositional system. Overbank alluvial plain fines are rare and insignificant or they are absent. Plant roots and trace fossils are very rare in braided river depositional system, due to unfavourable living conditions and extremely low preservational potential. This system shows many similarities that described by Jones *et al*. (2001) from the Miocene Rio Vero Formation of Spain. It implies deposition in broad, low-sinuosity, perennial but seasonal moderate-energy streams.

ALLUVIAL — MEANDERING AND ANASTOMOSING RIVER DEPOSITIONAL SYSTEM

This depositional system is characterised herein based on two exposures: Sołtyków exposure and borehole (Fig. 6; Pls. XI, 4, 5, 6; XII, 1) and Gromadzice exposure (Fig. 11; Pl. XI, 7). Sołtyków exposure shows many similarities to a meandering river alluvial plain with avulsion processes (Smith *et al*.,

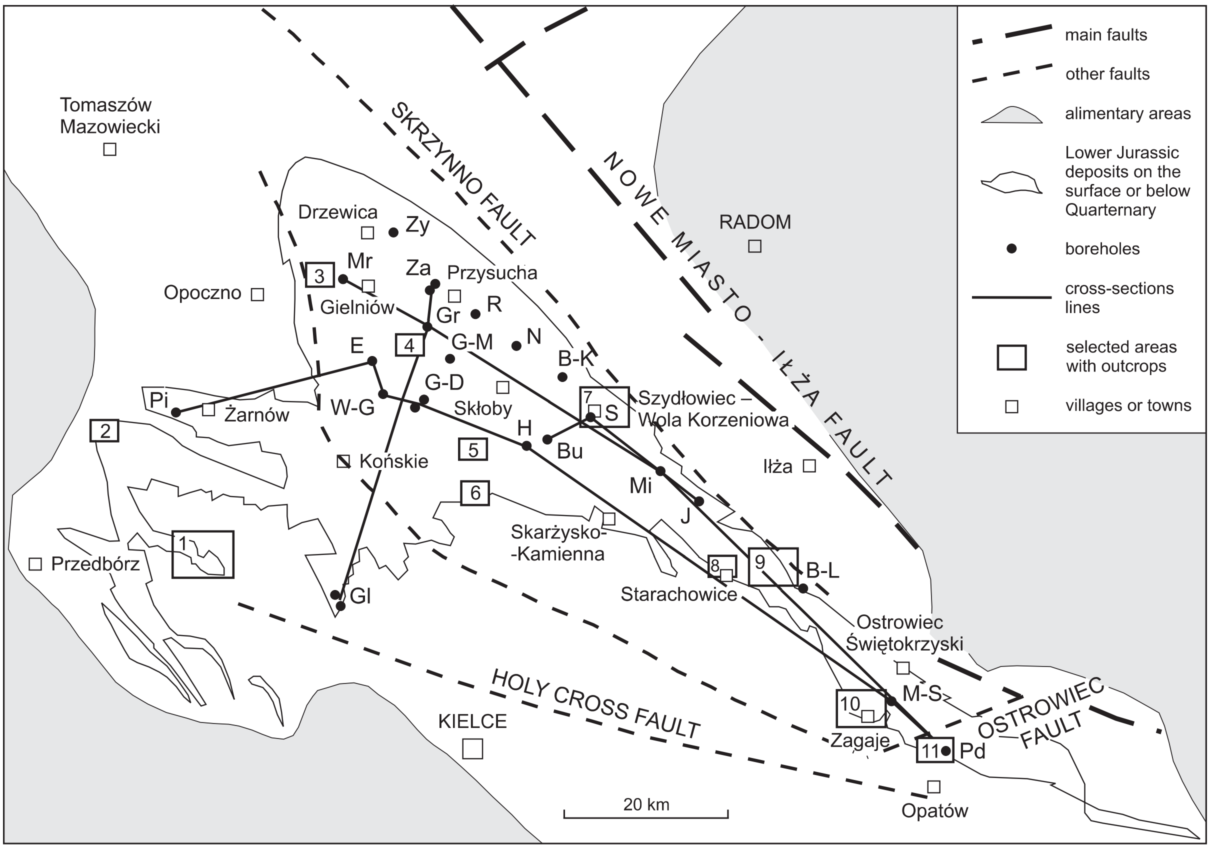


Fig. 20. Location of studied exposures and boreholes in the Holy Cross Mts region (tectonic map after Hakenberg, Świdrowska, 1997)

Exposures: **1** — Szkucin Lipa; **2** — Wolica; **3** — Bielowice; **4** — Zapniów; **5** — Niekłań/Piekło; **6** — Sołtyków; **7 —** Szydłowiec–Śmiłów area**; 8** — Starachowice; **9** — Adamów; **10** — Gromadzice; **11** — Podole.

Boreholes: **Pl** — Pilichowice P-1; **Mr** — Mroczków-Kraszków 160; **Gl** — Gliniany Las 1 and Gliniany Las 2; **E** — Eugeniów-Korytków; **W-G** — Wola Nosowa-Gąsiorów WG-2; **Zy** — Zychorzyn; **Gr** — Gródek OP-2; **Za** — Zawada PA-3 and Zawada ZA-9; **G-D** — Głęboka Droga 2; **G-M** — Gajówka-Modrzew; **R** — Ruszkowice K-2; **N** — Ninków; **H** — Huta OP-1; **Bu** — Budki 1; **B-K** — Broniów-Krawara SP-4; **S** — Szydłowiec N-1; **Mi** — Mirzec Mkr; **J** — Jagodne 1; **B-L** — Brody-Lubienia; **M-S** — Miłków-Szewna; **Pd** — Podole OS-3 (profiles of boreholes Gajówka-Modrzew, Ruszkowice, Ninków and Broniów-Krawara are not published herein, however, some specimen taken from these boreholes are illustrated in this paper)

1989; Farrell, 2001). This depositional system is widely developed in the lower part of the Zagaje Formation (Lower Hettangian) all over the Holy Cross Mts region (Huta OP-1 borehole, depth 120.0–190.0 m — Fig. 21 CD, Eugeniów-Korytków borehole, depth 96.0–121.0 m — Fig. 22 CD). A modern analogue of the meandering (high-sinuosity) — anastomosing river depositional system with prominent avulsion processes is presented in Fig. 12.

Channel-fill subsystem

Meandering channels exhibit the features most commonly associated with alluvial sedimentation (Galloway, Hobday, 1996). The channel floor, the deepest part of the channel, is characterised by a channel lag consisting of locally derived mud clasts, waterlogged plant debris and coarse bed-load gravel and sand — depending on their availability. Sand transport in meandering channels is dominantly by dune migration. Hence, grey medium- to large-scale trough cross bedded sandstones rich in plant detritus is the most characteristic lithofacies for channel fill deposits (Figs. 6, 11; Pl. XI, 5, 7). The size of bed-sets and grain size decreases upward which produce characteristic fining-upward, channel fill cycles composed of channel lag, point-bar sand and topstratum sediment (Allen, 1964b; Beerbower, 1964; Jackson, 1976; Galloway, Hobday, 1996; Miall 1996). Lateral accretion beds, identical to those presented by Jackson (1978) and Galloway, Hobday (1996, their fig. 4.8) characterise the Polish Early Jurassic point-bar deposits (Fig. 6; Pl. XI, 5). Fine sand, silt and some clay is deposited along the margins of the channels as decelerating, suspended-load-rich waters spill over the banks. Best examples of the alluvial channel subsystem come from the lower part of lower Gromadzice exposure (Fig. 11; Pl. XI, 7) and from the Sołtyków exposure (Fig. 6; Pl. XI, 5). The lower part of the lower Gromadzice exposure comprises mixed meandering/anastomosing alluvial plain with channel depositional subsystem (medium to poorly sorted, trough-cross bedded, laterally accreted sandstone lithofacies) with underlying both type 1 and type 2 crevasses (Fig. 19 CD, depth 72.7–72.9 m; Farrel, 2001). The fact that the type 2 crevasse appear in the uppermost part of the section, indicates growing aggradational/avulsion tendency associated with the rise of base-level (e.g. Aslan, Autin, 1999). Sandstones are rich in plant detritus (sometimes represented by log fragments up to 1 m long) and contain characteristic large *Parabrontopodus* tracks. The alluvial channel subsystem is associated with the floodplain subsystem represented by dark-grey to black mudstones with abundant plant detritus, palaeosoils with plant roots and Unionoidea freshwater bivalve assemblage. In the Sołtyków exposure a channelised body of poorly-sorted sandstone lithofacies with lateral accretion bedding is encased in the floodplain muddy subsystem (Pl. XI, 5). The presence of sand sheets at the beginning of the channel development (Fig. 6, depth 4.0–12.0 m; Fig. 19 CD, depth 72.7–72.9 m; Fig. 21 CD, depth 179.5–179.8 m) is noteworthy. These rapidly deposited sand sheets are interpreted as crevasse splay sediments. According to the avulsion model (Smith *et al*., 1989; Farrel, 2001) the sand sheets represent an initial avulsion stage accomplished predominantly by the development of crevasse splay complexes which cause the enlargement of new channels and abandonment of old ones. Thus the sedimentation in Sołtyków (Fig. 6) and in the Huta OP-1 borehole (depth 120.0–180.0 m — Fig. 21 CD,) is compatible with the avulsion-controlled fluvial sedimentation model of Smith *et al*. (1989), Aslan and Autin (1999) and Farrel (2001). On the other hand, the presence of laterally-accreted bedding within the channel depositional subsystem (Pl. XI, 5) and general domination of sharply based, "type 1" crevasse splays (Fig. 6; Pl. XI, 4, 6) point to lateral accretion and overbank flooding — i.e. sedimentation processes typical of meandering, not anastomosing/avulsion regime. As the anastomosing/avulsion model does not preclude some lateral migration of channels (Aslan, Autin, 1999), the Sołtyków exposure represents rather anastomosing/avulsion-dominated pattern of alluvial plain. Above all, the general lithofacies architecture (Pl. XI, 4) is characteristic for crevassing — anastomosing/avulsion processes (Smith *et al*., 1989; Pieńkowski, 1991b) and for high rates of fluvial aggradation and fluvial avulsion rate. It is also noteworthy, however, that the avulsion/anastomosing alluvial sedimentation pattern and high sinuosity/meandering/overbank deposition alluvial sedimentation pattern are sometimes difficult to be separated from each other, particularly in isolated borehole sections or in limited exposures.

Levee subsystem

Increments of sediment are built up with each successive flood to form natural levees. Some examples of levee deposition are known from the Sołtyków exposure and borehole (Fig. 6), and from several other boreholes (Eugeniów-Korytków borehole, depth 96.0–99.0 m — Fig. 22 CD), but the preservation potential of levee deposits is rather low, as they are prone to subsequent erosion. Lithofacies of modern natural levees are dominated by fine sandstones, siltstones and mudstones with ripple, climbing ripple, wavy and planar lamination. Plant roots associated with the Podzol type of palaeosoil (Arndorff, 1993) are associated with this subsystem.

Crevasse splay subsystem

Local breaches in the levees funnel the flow from the channel during the flood and provide conduits for suspended- and bed-load sediment dispersal into near-channel portions of the floodplain (Galloway, Hobday, 1996). Small anastomosing, distributary or braided channel systems extend across the splay surface, and both channelised and unconfined flow occurs during flood event, often forming local alluvial fans or "microdeltas" (Fig. 12). Crevasse splay models were characterised in details by Farrell (2001). According to that author, the problem with defining crevasse splays is that two processes can produce the same landform: (1) the sudden incursion of sediment-laden water; or (2) the basinward progradation of a minor mouth bar/crevasse channel couplet. In the alluvial subsystem of the Early Jurassic sediments of Poland the first process seems to play more prominent role, as most of the crevasse splay deposits show pronounced erosional and strong current features in their bases as mud clasts and parting lineation (Fig. 6). In Early Jurassic alluvial sediments of Poland crevasse splays are frequent. Classic crevasse splay deposits occur in Sołtyków exposure (Fig. 6; Pls. XI, 4, 6; XII, 1), they are also known from boreholes (Figs. 19 CD, depth 103.0–107.0 m; 21 CD depth 120.0–183.0 m). Most characteristic lithofacies of crevasse splay deposits comprise poorly-sorted sandstones with trough cross bedding and ripple drift cross lamination, although their internal structure is usually heterogeneous. They often contain mud clasts. Splays are sedimentary "garbage piles", accumulating large amounts of plant debris and mud clasts. Grain sizes and unit thicknesses are generally less than those of associated channel subsystem deposits (Fig. 6; Pls. XI, 4–6; XII, 1). Palaeosols of the Podzol type (Arndorff, 1993) and plant roots are abundant (Pl. XII, 1). Crevasse splay subsystem was particularly favourable for preservation of the dinosaur footprints (Pieńkowski, Gierliński, 1987; Gierliński, Pieńkowski, 1999; Gierliński *et al*., 2001b; see also the previous chapter). Also invertebrate burrows concentrate mostly in levee and crevasse splay deposits (Fig. 6), and to lesser extent in floodplain deposits.

Floodplain depositional subsystem

Fine bed-load to suspended load sediment is deposited in the floodplain as "overbank" sediments during floods. It should be noted, that Aslan and Autin (1999) believe that avulsion, rather than simple overbank deposition, contributes to the construction of fine-grained floodplains to a greater degree than generally recognised. The most frequent lithofacies is represented by dark, organic-rich, laminated mudstones (Pls. XI, 4–6; XII, 1). They are usually deposited in shallow lakes or backswamps, thus, as far as concerns lithofacies, the floodplain depositional system and lacustrine depositional system are often very similar or identical (Figs. 21 CD, depth 32.5–184.0 m; 22 CD, depth 56.0–117.0 m; 23 CD, depth 51.6–53.2 m). Classic examples of floodplain deposits are described from the lower part of lower Gromadzice exposure (Fig. 11) and Sołtyków exposure (Fig. 6; Pl. XII, 1). Mudstones are dark-grey to black, laminated or of a massive appearance, with numerous plant roots. Plant growth and pedogenic processes often obliterate primary structures. Levels with abundant small siderite concretions ("siderite sphaerulites") represent characteristic, early diagenetic product of pedogenic processes in this permanently saturated soil. Plants represent largely a wetland association, also of a character of "reed swamp". Shallow water tables occurring in backswamps or oxbow lakes (Fig. 12) created favourable conditions for deposition and preservation of plant debris, which is typical for the Gleysol type of palaeosol (Arndorff, 1993). Mudstone lithofacies are similar to those described by Schieber (1999) from the Upper Devonian floodplain deposits.

LACUSTRINE DEPOSITIONAL SYSTEM

This system does not differ much from the floodplain depositional subsystem described in the previous chapter — generally, the sediments tend to be more fine-grained than in floodplain depositional system (Fig. 21 CD; depth 32.5–120.0 m). Dominating lithofacies are represented by dark-grey and olive-grey, laminated mudstones and claystones, sometimes with varve-like lamination (Pl. III, 1). Gleysol type of palaeosols with abundant plant roots and well-preserved plant fragments transformed into coal intercalations are characteristic for this depositional system.

TRANSITION BETWEEN THE ALLUVIAL DEPOSITIONAL SYSTEM AND THE DELTAIC DEPOSITIONAL SYSTEM

The lower Gromadzice outcrop (Fig. 11) reveals a remarkable sequence of alluvial depositional system and upper delta plain depositional subsystem. The lower part of the outcrop comprises typical meandering (high-sinuosity) alluvial channel subsystem with trough-cross bedded sandstone revealing bounding, lateral accretion bedding (see the previous description of alluvial meandering depositional system). In the nearby Miłków-Szewna borehole (Fig. 19 CD, depth 70.0–74.0 m), these channels are associated with "transitional", coarsening-upward crevasse splay deposits below the channel base, which points also to avulsion processes. On the other hand, some other crevasses in this complex show erosional bases (Fig. 19 CD, depth 74.8–76.0 m). This system (Fig. 19 CD; depth 71.0–115.0 m) was dominated by mixed crevasse processes (Farrel, 2001), and development of lateral channel migration shows that there was an equilibrium between vertical and lateral sediment accretion rate (Collinson, 1978; Aslan, Autin, 1999).

The overlying complex of grey, laminated mudstones, siltstones and grey, fine-grained sandstones are of different character. Laterally-continuous layers of siltstones and sandstones show coarsening-upward character, some low-angle bounding surfaces and tabular cross bedding sets showing directions of transport dispersed between West and North directions. Notably, there is lack of erosional features at the bottom of each cycle. Such pattern is substantially different in comparison to crevasse splay deposits described from the alluvial system (Sołtyków outcrop — Fig. 6, Pl. XI, 4, 6). It points to the basinward progradation of a minor mouth bar/crevasse channel couplet (Farrell, 2001), which results is a sequence resembling deltaic crevasses (bayfill analogue). Such successions are 50 cm–1 m thick and include a mud facies overlain by lenticular lamination, laminated silt and cross bedded/laminated, fine-grained, poorly-sorted sandstones. Plant debris occurs in the whole sequence and plant roots are most abundant at the coarse-grained, top parts of each sequence. Bivalve finds shed light on the character of the mudstones. The bivalve assemblage contains both fresh-water Unionoidea and rare brackish-water Cardiniidae and Mytilidae. Additionally, boron content is slightly higher than in the underlying alluvial plain mudstones. Interestingly, numerous dinosaur tracks found in the section represent the *Anomoepus–Moyenisauropus–Anchizauripus–Grallator* association (Pl. VIII, 2). The tracks were left by small- to medium sized low-browsing animals belonging to basal ornitishians and small- to medium-sized theropods. This assemblage is regarded as typical of delta plain and barrier-lagoon deposits (Gierliński, Pieńkowski, 1999). Collectively, all those features point to a delta plain (upper delta plain) deposit, where the muddy overbank plain was at least periodically occupied by brackish water with a "bay bivalve" association. Sandstone/siltstone layers represent deltaic, basinward prograding crevasse splay deposition. These features are consistent with rapid aggradation during which crevassing, lacustrine/marsh sedimentation, and avulsion dominated delta plain/floodplain construction in the Holocene Mississippi river floodplain (Aslan, Autin, 1999).

It is noteworthy that the change of depositional system from alluvial plain to delta plain is very gradual, without a "clear" transgressive surface. It should be mentioned, that the "clear" or "true" transgressive surface can be noted (particularly in boreholes) when nearshore deposits cover the continental (alluvial/lacustrine) deposit. In the Gromadzice outcrop (Fig. 11) only types of crevasse development, meandering/avulsion character of faces architecture and biofacies/chemofacies characteristics make a difference. However, contact between the two successions exposed in Gromadzice represents change from alluvial (mixed lateral accretion-avulsion controlled) to deltaic-alluvial (highly aggradational, avulsion-dominated) depositional system. Some 5 metres above this sequence, a well-defined transgressive surface occurs (recognisable also in Miłków-Szewna borehole, depth 69.2 m — Fig. 19 CD) with contact between delta plain/lacustrine deposits and offshore embayment sediments above (Pieńkowski, 1991a, his fig. 2.1). Such a change in facies, immediately preceding the transgression, suggests a slight diachroneity of transgressive surface in a regional scale (Figs. 24, 25).

TRANSGRESSION AND ITS NONMARINE CORRELATIVE SURFACES WITHIN ALLUVIAL/LACUSTRINE/DELTA PLAIN DEPOSITIONAL SYSTEMS

Good correlation between transgression and transgressive surface can be observed basinward, in Pomerania and the Danish basin (Fig. 26), where the marine sediments lie sharply on alluvial deposits (ravinement surface), without any "transitional facies" predating the transgression — compare with Catuneanu *et al*., 1998. At the same time, a rapid base level rise has a pronounced effect on sedimentation in the continental basin — alluvial deposition is rapidly replaced by a fine-grained, lacustrine deposition and consequently, the nonmarine correlative surface (time equivalent) of transgressive surface can be observed within continental deposits (Figs. 24, 25, 26 — see the correlative surfaces marked with green lines). Change from an alluvial depositional system with laterally shifting fluvial channel belts to highly aggradational lacustrine depositional system or avulsion-dominated alluvial plain system, associated with a base level rise, is confirmed in many works (Shanley, McCabe, 1994; Olsen *et al*., 1995; Surlyk *et al*., 1995; Aslan, Autin, 1999). Further progress of a transgression leads to development of nearshore depositional systems overlying lacustrine depositional systems. A scheme of such "step-wise", retrogradational development of transgression (transgression systems tract) with its nonmarine correlative surfaces within alluvial and deltaic systems is particularly well recognised within the depositional sequence I in the Holy Cross Mts region and is presented in Figs. 25 and 26. The succession of retrogradational continental deposits occurring between the nonmarine correlative surface within continental deposits and the transgressive surface at the base of marine/nearshore deposits was named tentatively as the "pre-transgressive systems tract" (Pieńkowski, 1991a; 1997). Such aggradational/retrogradational succession of sediments belongs to the transgressive systems tract, although it occurs below the transgressive surface (Figs 25, 26). It should be noted, that the present work documents non-marine correlative of the transgressive surface, which has been regarded as unidentifiable within the fluvial succession (Catuneanu *et al*., 1998). Surlyk *et al*. (1995) also claimed that distinguishing of correlative surfaces of marine transgressions is possible in fluvial/lacustrine facies (their lacustrine-flooding surfaces).

DELTAIC DEPOSITIONAL SYSTEM

A delta forms where a river transporting significant quantities of sediment enters a receiving basin. Interaction of subaerial fluvial (alluvial) processes and subaqueous processes of marine basins produces distinctive facies assemblages (Galloway, Hobday, 1996). Depositional architecture of a delta system is characteristically progradational, which typically results in coarsening-upward sequences. Sediment input (constructional processes — fluvial) and wave-energy flux (redistribution processes) controls the lithofacies and depositional subsytems distribution in delta systems (Postma, 1995). In

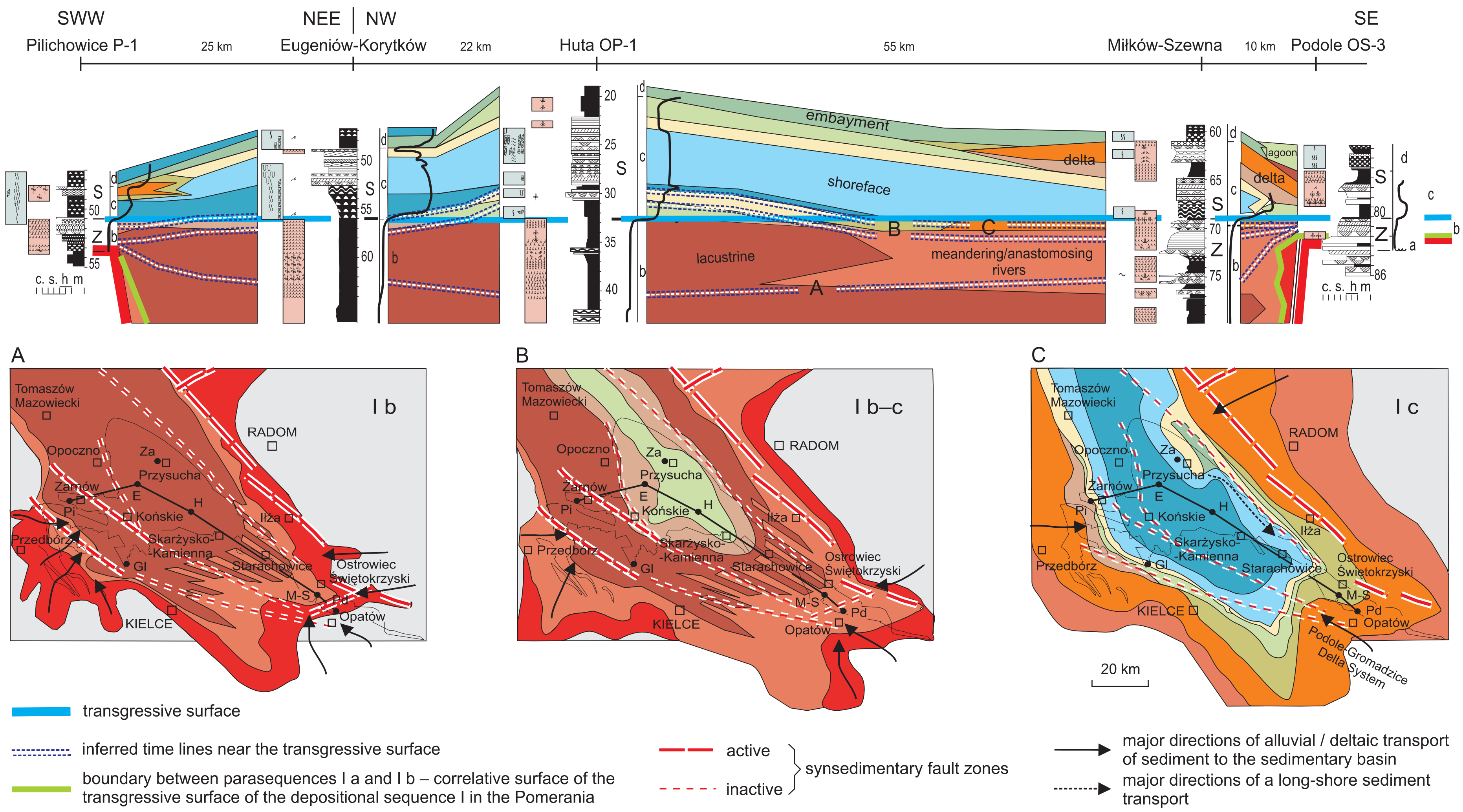


Fig. 24. Cross-section of the Holy Cross Mts region showing a part of depositional sequence I (b, c parasequences) and development of the Early Hettangian transgression correlated with the world-wide transgression in the *planorbis* Zone

Reference level — transgressive surface of the depositional sequence I. Three inferred time lines (from the bottom to the top) correspond with maps A, B, C, respectively. Gradual development of transgression is visible, with initial lagoonal transgression drowning the lacustrine depositional system in the basin's centre. Ensuing development of the brackish marine basin is shown on the map C. The figure shows a slight diachroneity of the transgressive surface in the Holy Cross Mts basin's (between the basin's centre and edges). For further explanation see Fig. 16

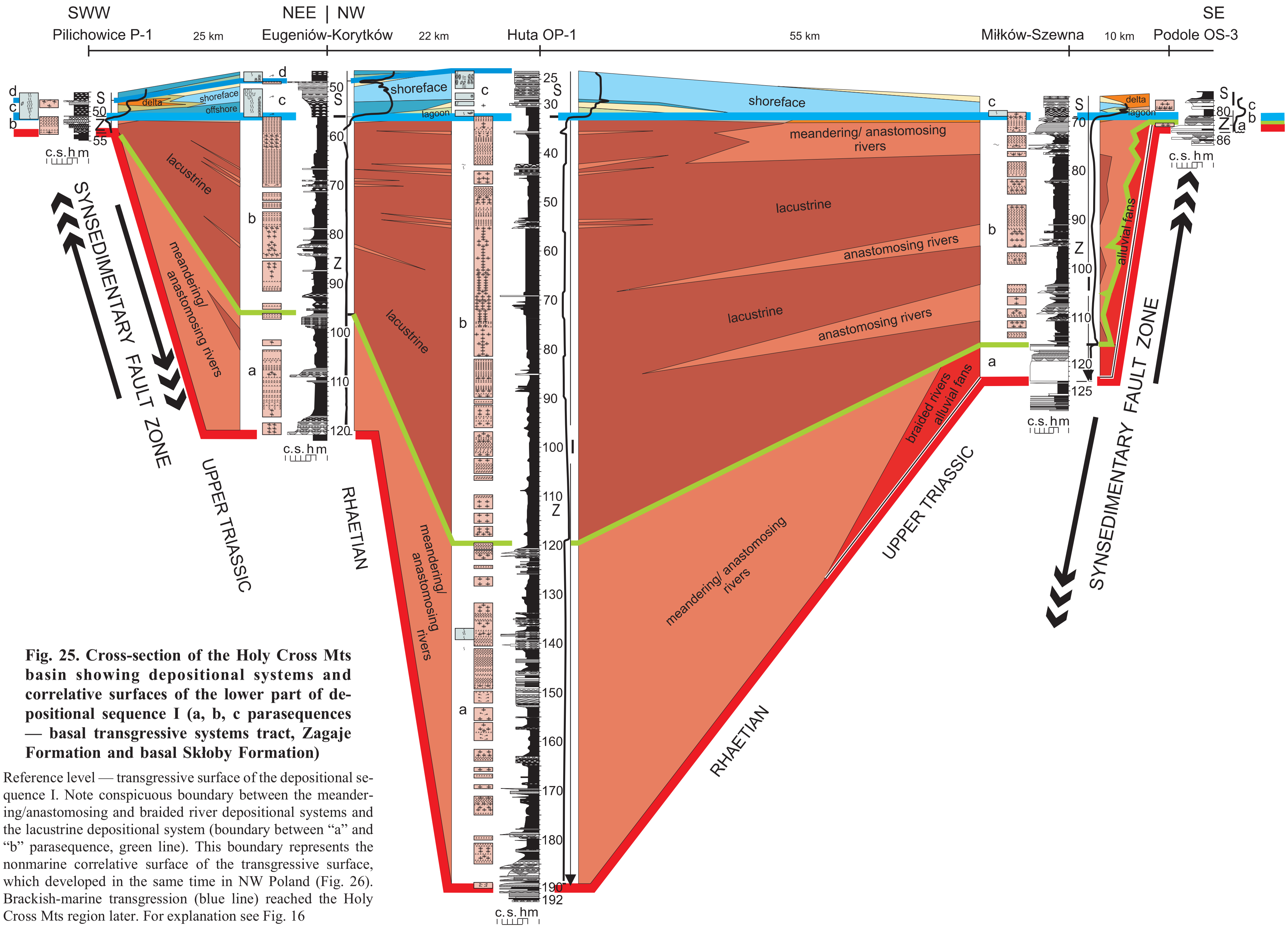


Fig. 25. Cross-section of the Holy Cross Mts basin showing depositional systems and correlative surfaces of the lower part of depositional sequence I (a, b, c parasequences — basal transgressive systems tract, Zagaje Formation and basal Skłoby Formation)

Reference level — transgressive surface of the depositional sequence I. Note conspicuous boundary between the meandering/anastomosing and braided river depositional systems and the lacustrine depositional system (boundary between “a” and “b” parasequence, green line). This boundary represents the nonmarine correlative surface of the transgressive surface, which developed in the same time in NW Poland (Fig. 26). Brackish-marine transgression (blue line) reached the Holy Cross Mts region later. For explanation see Fig. 16

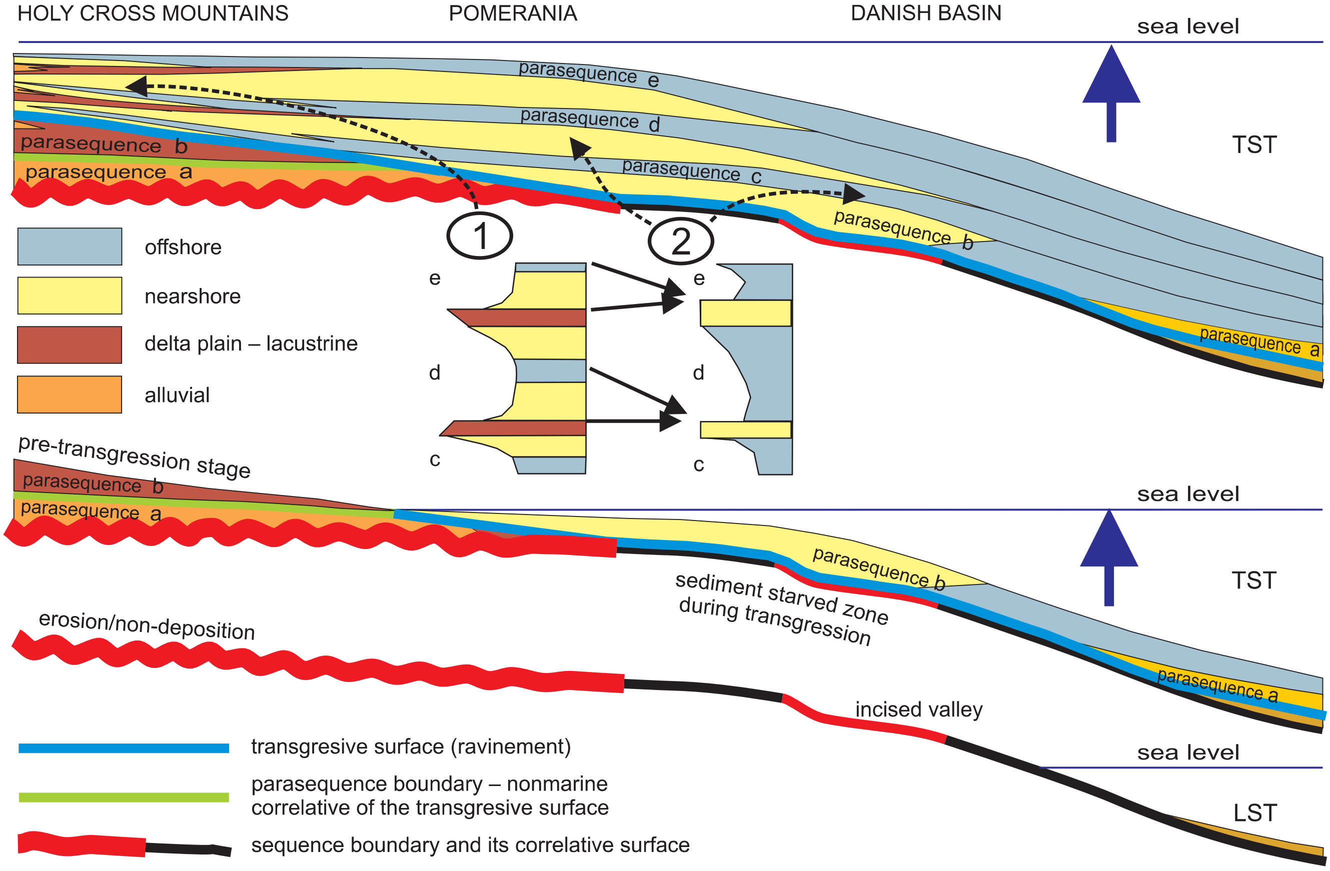


Fig. 26. Development of the transgressive systems tract (TST) of the depositional sequence I in marine (Danish Basin), marine to marginal marine (Pomerania region) and marginal-marine to continental settings (Holy Cross Mts region)

LST — lowstand systems tract (corresponding with erosion in the areas studied). Note the "backstepping" of sedimentary package in the initial phase of transgression, step-wise, retrogradational development of parasequences and rapid replacement of the alluvial depositional system by the aggradational, lacustrine/delta plain depositional system ("pre-transgression" stage), which is caused by the base-level rise. The coeval correlative surface of the transgressive surface, associated with the base level rise, can be observed within continental deposits (nonmarine correlative surface, green line). "Bifurcation" of transgressive surface and its nonmarine correlative surface separates a package of the aggradational, lacustrine/delta plain deposits between the nonmarine correlative surface and transgressive surface in the Holy Cross Mts (see Fig. 25). Note that a general style of parasequences is different in marginal-marine settings (type 1 parasequences) and in areas close to the marine basin (type 2 parasequences) — flooding surfaces in marine basin approximately correspond with parasequence maximum flooding stages, while in marginal marine settings these surfaces are apart from each other

deltaic system, the term "fluvial" is more appropriate, as delta constructioning processes are related mainly to river channels activity. All actively prograding deltas have at least one common attribute: a river supplies clastic sediments to the receiving basin more rapidly than they can be removed by marine processes (Coleman, 1981). As tidal activity was not prominent in the Early Jurassic basin in Poland, tide-dominated deltas do not occur. Therefore two basic types of deltas were distinguished in the Early Jurassic deposits of Poland: fluvial-dominated (birds-foot) deltas (Fig. 13), and wave-dominated (or mixed wave-fluvial) deltas (Fig. 14). The stratigraphical patterns in a small-scale delta complexes are distinguished by outcrop-scale lithofacies features (Figs. 8, 17). The deltaic cycles were formed by reoccupation-abandonment autocyclic processes. As far as concern palynofacies, the delta plain palynofacies is similar to the alluvial one. Delta front and interdistributary bay palynofacies show increased number of sporomorphs (Fig. 9; Pl. VI, 2). In the Early Jurassic deposits of Poland, the boron content is usually relatively low in comparison with other marginal marine depositional systems.

FLUVIAL-DOMINATED (BIRD-FOOT DELTAS)

Postma (1995, his fig. 5) distinguished twelve delta prototypes of fluvial-dominated deltas prograding in a low energy basin characterised by low wave energy, low littoral drift and high discharge of fines as suspended load. One of his types fits conditions occurring in the Early Jurassic epicontinental deposits of Poland. This is type D8, associated with shallow basins, with low-gradient, highly stable suspension-load rivers with levees. Birds-foot deltas built vertical sequences of regular, coarsening-upward character (Figs. 13, 17, 18 CD — Podole OS-3, depth 48.0–80.0 m). Such sequences represent prograding environments (subsystems) which can be ordered from the bottom to the top in the following way: prodelta (laminated mudstone and heterolith lithofacies), delta front — mouth bar (laminated to cross-bedded siltstones, heteroliths and fine-grained sandstones — Pl. XII, 3), interdistributary bay (organic-rich mudstones — Pl. XIII, 7), distributary channel (trough cross-bedded sandstones — Pls. XII, 2; XIII, 3, 4, 7) and complex delta plain subsystem, comprising flood plain deposits (organic-rich mudstones) and crevasse and levee deposits (ripple-laminated siltstones, cross-bedded sandstones) — Fig. 11, Pl. XI, 8. In all the depositional subsystems, Unionoidea bivalves are common with very rare, uncertain representatives of Cardiniidae in prodelta deposits, which points to freshwater — low oligohaline faunas (Hudson *et al*., 1995). In this type of delta system buoyant sediment plumes plays a very important role in development of subaqueous elements of delta (prodelta and delta front). The dispersal of sediment suspension off the front of a fluvial-dominated delta involves the transport of clay, silt and fine sand on a buoyant plume of fresh water that is propelled from the stream-channel mouth by an effluent jet and spreads basinward above a denser, saline or brackish, basinal water (Bates, 1953). The suspended sediment particles tend to settle out from the buoyant plume, giving rise to a continuous "rain" of fines that progressively cover the deltaic slope and prodelta zone. Mixing of fresh and brackish-marine water favoured flocculation processes (Gibbs *et al*., 1989). As the wave processes in the basin were not strong enough for a complete removal of the mud fraction in the sandstones, the fluvial-controlled delta front subsystem was the area where the characteristic "diffuse heteroliths" were formed (Pls. IV, 2; XII, 3). The "poor sorting" in the heterolithic facies (called "diffuse heteroliths"), is documented by an intermixing of fractions. The mud fraction occurs abundantly within the sandy lenses and laminae, while the sandy fraction is present in mud intervals. As a result diffuse contacts or low contrast between the sandy lenses and mudstones can be observed and the sandy lenses are irregular. The "diffuse heteroliths" were formed during quick sedimentation under continuous "rain" of sediment, while fluctuations in wave/current activity created heterolithic character of the sediment. Such "diffuse" heteroliths were described by Pieńkowski (1991b) from fluvial-dominated delta systems from Hettangian deposits from Southern Sweden. They seem to be characteristic lithofacies for delta-front depositional subsystem in fluvial-dominated deltas. Theoretical mechanism of activity of deltaic buoyant plumes was given by Nemec (1995). Interestingly, in fluvial-dominated delta system trace fossils spectrum is poor in dwelling structures (domichnia), due to a high concentration of suspended mineral matter, which is not favourable to suspension-feeders (Rhoads, Young, 1970; Pieńkowski, 1985). Plant roots (the Histosol type of palaeosol – Arndorff, 1993) colonise the topsets of deltaic cycles (Pl. II, 3, 5, 10), while trace fossils (mostly fodinichnia) are grouped mainly within prodelta and delta front subsystems. Characteristic dinosaur footprint associations occur within delta-plain deposits (see previous chapter). The distributary channel subsystem is very similar to alluvial channel subsystem (Pl. XII, 2), although general scale of sedimentary structures and maximum and medium grain size of bed load sediment are lower. Plant fragments are abundant in all depositional subsystems. Also palynofacies reflects the proximity of vegetation (Fig. 9). Examples of such a deltaic system is presented on Figs. 17, 18 CD, and summarised in Fig. 13. Deltaic deposition dominated the most marginal parts of the Early Jurassic brackish marine basin. It is possible to estimate the depth of the receiving basin in the case of Podole delta system (Figs. 17, 18 CD), based on the rule that the progradational sequence of sediments approximately reflects the local water depth. The average thickness of a delta cycle is 4 metres and the cycles are regular and continuous, comprising complete sets of depositional subsystems from prodelta to subaerial distributary and delta plain subsystems. Assuming the compaction factor of mudstones, siltstones and fine-grained sandstones (at the estimated burial depth of 800.0 m) as 1.4, the primary depth of the basin is estimated at about 5–6 metres.

INTERMEDIATE FLUVIAL- AND WAVE-DOMINATED DELTAS

Intermediate fluvial- and wave-dominated deltas occurred in basins of intermediate wave energy, apparent littoral drift and very flat offshore slope, with the same characteristics of fluvial influx as in the previous, fluvial-dominated type of delta system. Basinal processes reworked, modified and distributed sediments within the outer part of the delta, which resulted in a "composite" vertical sequence of individual delta-progradation cycles (upper Gromadzice exposure, Fig. 8). Individual delta cycles reflecting prograding subsystems are divided into two parts separated by flanking barrier belt-facies (reworked mouth bars) formed at the wave-breaking zone. The outer deltaic zone is composed of muddy and heterolithic prodelta deposits and sandstone flanking barrier deposits (delta-front zone, wave-reworked mouth bars). The inner deltaic subsystem is dominated by stagnant lagoons and interdistributary bays, with marshes and coal accumulation and poorly-drained types of palaeosols of Histosol to Gleysol type (Arndorff, 1993; Fig. 8; Pl. II). The lagoon-marsh deposits are overlain by quickly prograding, relatively low-energy distributary channels (Miłków-Szewna borehole, three cycles between 42.0 and 69.0 metres, separated by intervals of nearshore deposits — Fig. 19 CD). Progradational and flooding stages were connected with reoccupation-abandonment autocyclic processes, identical to those presented by Boyd and Penland (1984, their fig. 8). However, such fluctuations were responsible for composite vertical successions of stacked, aggradational or progradational cycles instead of simple coarsening-upward cycles (Fig. 17). Modern analogues (although in much bigger scale) are known from the Nile delta (Coleman *et al*., 1981) and Mississippi delta (Boyd, Penland, 1984). Spatial reconstruction of this delta type, showing progradational and flooding stage, is presented on Fig. 14. As in all deltas, plant roots and plant debris are abundant in inner delta zone, but they are less frequent in outer delta zone. Also domichnia appears in the outer delta (barrier) zone (Fig. 8), while they are generally absent from delta-front subsystem in birds-foot deltas (Fig. 17). Bivalve association shows a characteristic "mixed" character — both Cardiniidae (mostly *Cardinia follini* Lungren) and Unionoidea are present, pointing to low oligohaline faunas (Hudson et al., 1995). It points that the Unionoidea bivalves were not confined to fresh water but could occur in some abundance in low-oligohaline waters. Numerous dinosaur footprints of *Anomoepus–Moyenisauropus–Anchizauripus–Grallator* association occur in the delta plain (inner delta) zone. This type of delta depositional system is rather poorly known from previous work, particularly in vertical sequences from the geological record. Best counterparts were described by Horne *et al*. (1978, their fig. 1), Pieńkowski (1991b, his fig. 7; pl. 9) and Emery, Myers (1996, his fig. 8.10).

Development of this deltaic succession, particularly at the contact between coal and distributary channel facies (Fig. 8), allows some conclusions concerning time span and accommodation space. Large-scale autocyclicity such as delta switching generates coals of subregional extent (Hamilton, Tadros, 1994). A contact between coal or peat and clastic sediment usually represents a considerable hiatus in clastic deposition (McCabe, 1984). For peat to form, the rate of increase of vertical accommodation space must equal the rate of accumulation of peat, and clastics must be excluded from the environment (Bohacs, Suter, 1997). In some interpretations of deltaic deposits, the contact between coal or peat and overlying clastic sediments usually represents a regional flooding surface (Farrell, 2001). Other authors (Coe *et al*., 2003) identify bottoms of coal seams occurring in delta plains with flooding surfaces. However, in the Gromadzice exposure (Fig. 8) three different contacts between coal and clastic sediments occur in one profile. The lowermost contact (3.25 m) represents flooding of a backbarrier marsh by a lagoon/interdistributary bay, caused by local rising of water table associated with basinward migration of a flanking barrier/mouth bar. It represents a local flooding stage, associated with local creation of some accommodation space and fine-grained clastic sedimentation, but certainly it does not represent a regional flooding surface. The second contact (2.20 m) is associated with erosion (Fig. 8, surface marked with "**e**"), and in this case the clastic sediment supplied by autocyclic processes (delta lobe switching), which stops peat production and generates a facies contact cannot be identified with a regional flooding surface or any flooding stage (see Farrell, 2001). Oppositely, the facies transition represents rapid progradation of a low-energy distributary channel facies onto lagoon/marsh deposits. Peat accumulation (occurring probably in a water-logged reducing environment of a permanently saturated palaeosol, where plant growth catched up with sedimentation – note very long plant roots) was stopped shortly before progradation of the distributary channel. This model requires that the coals be initiated as low-lying coastal swamps behind the shoreline. Subsequent accumulation of distributary channel facies needed some accommodation space, which was created by subsidence, largely associated with gradual compaction of underlying clays and peats. The uppermost contact represents true, "classic" regional flooding surface – the delta plain backswamp was flooded by brackish-marine basin, which rapidly stopped peat production and led to deposition of clastic sediments. The Gromadzice exposure (Fig. 8) shows three coal/clastic sediment contacts in one delta progradational cycle, developed accordingly to the classic Walther's rule. Therefore, contacts between peat and overlying clastics, although they always form conspicuous marking horizons, must be treated with due caution concerning their proper interpretation. Despite the fact that the coal seams in marginal-marine settings usually herald local or regional sea level rises, the character of facies lying above the coal/clastic sediment contact and careful studies of the whole succession is crucial in that respect.

A high degree of wave reworking and basinal processes can lead to near total redistribution of fluvio-deltaic sediments. In such cases it is hard to differentiate such systems as deltaic ones, particularly in boreholes, and the wave reworked sediments were usually regarded as representing the nearshore or barrier-lagoon depositional system. Therefore, the interpretation of palaeoenvironments (depositional systems) in Early Jurassic sediments of Poland may be slightly biased towards a "non-deltaic" interpretation.

BARRIER-LAGOON DEPOSITIONAL SYSTEM

Barrier coast successions reflect three main environments (depositional subsystems): — the shore parallel barrier islands or spits, including eolian dunes, back-barrier eolian sheets and washover fans behind the barrier/spit crest; — the enclosed lagoon or embayment; — inlets that facilitate exchange of storm-driven circulation (Galloway, Hobday, 1996). Tidal activity is not discussed widely as it is of rather lesser significance in Early Jurassic epicontinental basin in Poland. Moreover, barrier islands and spits are best developed in tideless or microtidal shore zones (Hayes, 1975). The origin of barriers has been attributed to at least three different mechanisms (Hoyt, 1967; Swift, 1975; Wilkinson, 1975): — the vertical growth and emergence of offshore bars; — downdrift growth of spits; — detachment of beach ridges from the mainland by a rise in sea level. What is characteristic for the barrier-lagoon systems is the presence of lagoonal deposits, separated from the open basin by a belt of nearshore/barrier deposits. An excellent modern analogue of barrier/spit/lagoon/ embayment system from the Baltic coast of Poland is presented in Fig. 15.

BARRIER DEPOSITIONAL SUBSYSTEM

The basinward part of the barrier-lagoon depositional system is treated as part of the nearshore depositional system (see the next chapter). Microtidal or tideless barriers tend to belong and narrow, with conspicuous washover fans and few inlets. Barrier lithosomes depend very much on the wave energy in the basin. Lower wave energy leads to preservation of more complete barrier profile reflecting palaeomorphology (Pl. XIII, 3, 4). Beach deposits with low-angle tabular foresets and barrier crest eolian dunes with buried plants are often preserved (Pls. II, 6; XIII, 4, 6, 7). High energy produces more inlets and washover fans and destroys barrier crest deposits, which results in dominance of trough-cross bedding sets within the preserved barrier body (Pl. XIV, 6). Yet another kind of barrier is a submerged type (Pl. XII, 5). These are unstable and quickly translocating forms, separating open basin from an embayment or embayment from a lagoon. In the Polish Early Jurassic such submerged barriers modified the dynamic conditions during fair-weather but did not form a significant obstacle during increased wave action (Pieńkowski, 1991b) and were breached during very strong storms. Their vertical profile is usually "incomplete", without coarse, foreshore and backshore deposits of barrier crest — for example Pl. XII, 5; Figs. 16, 27 CD (Wola Nosowa-Gąsiorów WG-2, depth 20.0–23.5 m) and 28. Their tops show sometimes dolomite cementation. Submerged barriers or bars may belong both to shoreface or foreshore depositional subsystems.

LAGOON DEPOSITIONAL SUBSYSTEM

The lagoonal environment is highly variable depending on hydrological conditions. The barrier belt or spit separates the lagoon from the open basin with different effectiveness. A continuous barrier belt is associated with a closed lagoon characterised by low energy sedimentary processes, dark, often oxygen-depleted sediments, frequent well-preserved plant fragments (which indicates a calm sedimentary environment), poor and infrequent fauna, limited bioturbation, frequent siderite bands and nodules (Pls. II, 4; V, 6). Therefore, lagoonal sediments are represented by dark-grey to brown-reddish mudstones. Mudstones are finely laminated. Lenticular lamination is common, other heteroliths are rare. A relatively high admixture of iron in siderite and sideritic mudstone beds is caused by proximity of marsh/swamp areas, a prominent source of iron. This results in the occurrence of secondary reddish colours, which is the effect of epigenetic oxidation. If there is a river mouth on the landward shore of the lagoon (a so called "bayhead delta"), the lagoon is usually quickly infilled by deltaic/alluvial sediments (Roy *et al*., 1980) — for example Fig. 18 CD (Podole OS-3, depth 34.0–55.0 m). Palynofacies (Pl. VI, 2) are rich in both opaque phytoclasts and cuticle. Number of palynomorphs, particularly spores sometimes (hydrodynamic traps) is very high.

Boron content can be very unstable in such deposits (Gliniany Las 1, depth 10.0–35.0 m — Fig. 5 CD). It is caused either by evaporation (in case of high contents) or influx of fresh water (in case of low contents).

MARSH DEPOSITIONAL SUBSYSTEM

Plant roots and palaeosols are common in shallow parts of the lagoon subsystem, which leads to formation of marsh depositional subsystem with accumulation of dark-grey mudstones with plant roots (Pl. II, 1, 2, 8, 9a, b, 11) and brackish marsh peat. Siderite nodules are common, but also pyrite concretions occur, which differentiates the marsh mudstones from fresh-water lacustrine mudstones. Both mottled and laminated (lenticular silty lamina) structures occur (Schieber, 1999). Marsh subsystems tend to contain more boron as this element is absorbed by organic matter (Uličny, 1989).

EMBAYMENT DEPOSITIONAL SUBSYSTEM

If the contact with sea is wider (such as in the case of spits), lagoons are transformed into embayments and their sediments show higher energy of depositional processes, which causes much frequent presence of heteroliths. Colour of sediments is paler, and in places bioturbation by deposit-feeding organisms is high, which leads to obliteration of primary sedimentary structures. Plant fragments, coal and plant roots are less frequent than in the deposits of closed lagoon, as are sideritic bands. Palynofacies show transitional character between closed lagoons and open basin (Fig. 9).

Gradual transgression, with development of lagoon, embayment, barrier and offshore-shoreface sediments in one vertical section occurs for example in Gliniany Las area (Fig. 16 — above the flooding surface) and in Miłków-Szewna borehole (depth 35.0–42.0 m — Fig. 19 CD). It is important for defining of the parasequences in marginal-marine settings, which will be discussed later.

The barrier-lagoon depositional system occurs in both transgressive (retrogradational) and high-stand (progradational) systems tracts. Transgressive surfaces and flooding surfaces are often associated with development of barrier-lagoon depositional systems, particularly when the sediment input to the basin was relatively high. Barrier-lagoon system is regarded as typical of transgressive coasts (Boyd et al., 1992). Examples are numerous: Gliniany Las area (Fig. 16), Huta OP-1 borehole (Fig. 21 CD, depth 10.0–32.0 m, with flooding surfaces of Ic and Id parasequence); Eugeniów-Korytków borehole (Fig. 22 CD, depth 48.0–52.0 m, with flooding surface of Id parasequence), Eugeniów-Korytków borehole (depth 45.0– 50.0 m), Wola Nosowa-Gąsiorów WG-2 borehole (Fig. 27 CD, depth 55.0–63.0 m with flooding surface of Id parasequence), Eugeniów-Korytków–Wola Nosowa-Gąsiorów area (Figs. 28, 29).

There are also examples of "regressive" barrier-lagoon depositional systems associated with progradational high- stand systems tracts or regressive, progradational tops of parasequences. However, such situations seem to be less frequent. Examples are shown in: Eugeniów-Korytków borehole, depth 9.0–13.0 m, and Wola Nosowa-Gąsiorów WG-2 borehole, depth 18.5–20.0 m.

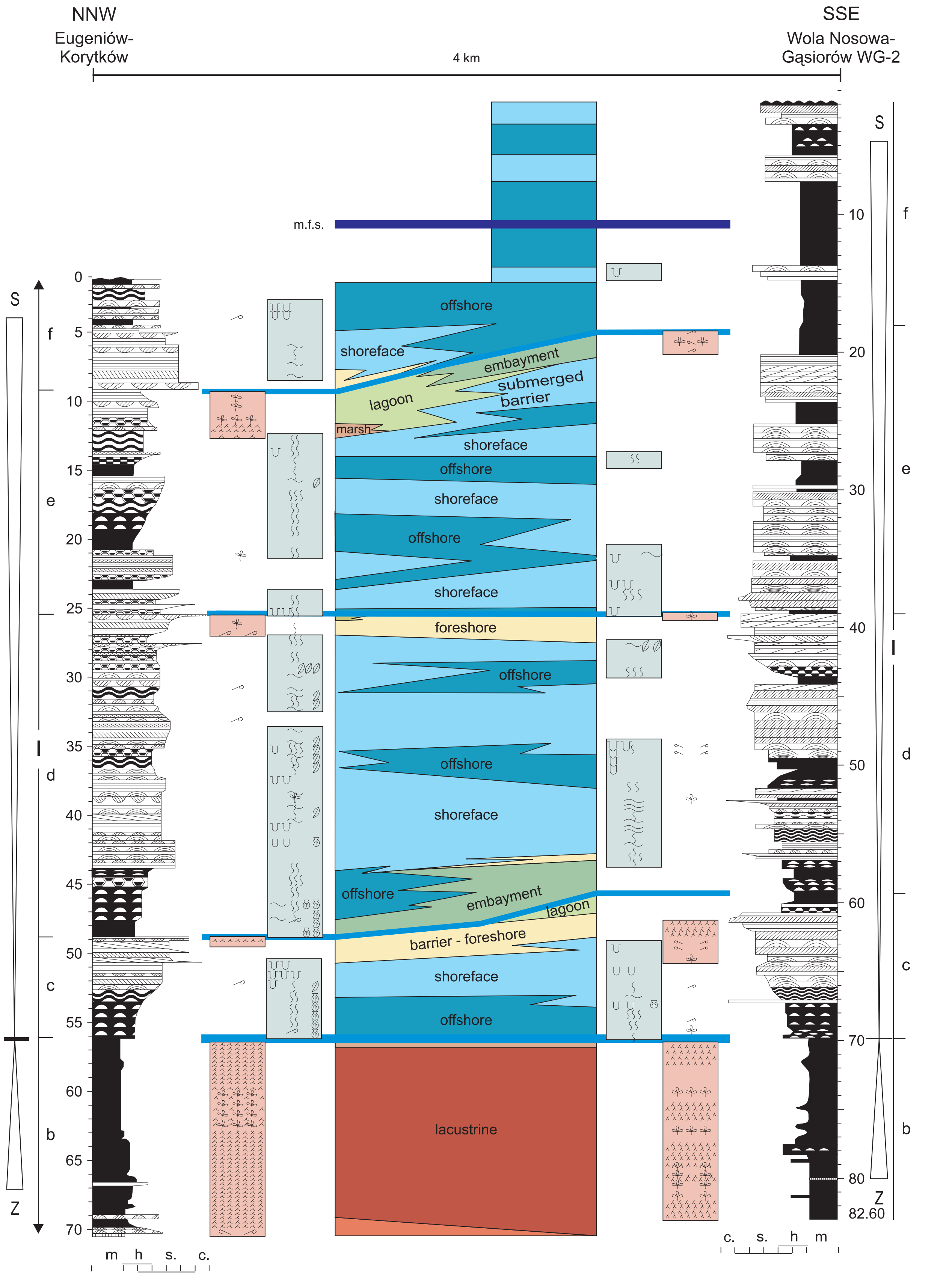


Fig. 28. Cross-section between Eugeniów-Korytków and Wola Nosowa-Gąsiorów WG-2 boreholes (depositional sequence I b–f), showing changes of lithofacies and depositional systems/subsystems at a distance of 4 km

Note that many lithofacies and depositional subsystems (local sedimentary cycles) wedge out, while parasequences, parasequence boundaries (flooding surfaces) and maximum flooding surface of sequence I are of correlative significance. Reference level — transgressive surface of the depositional sequence I. For explanation see Fig. 16

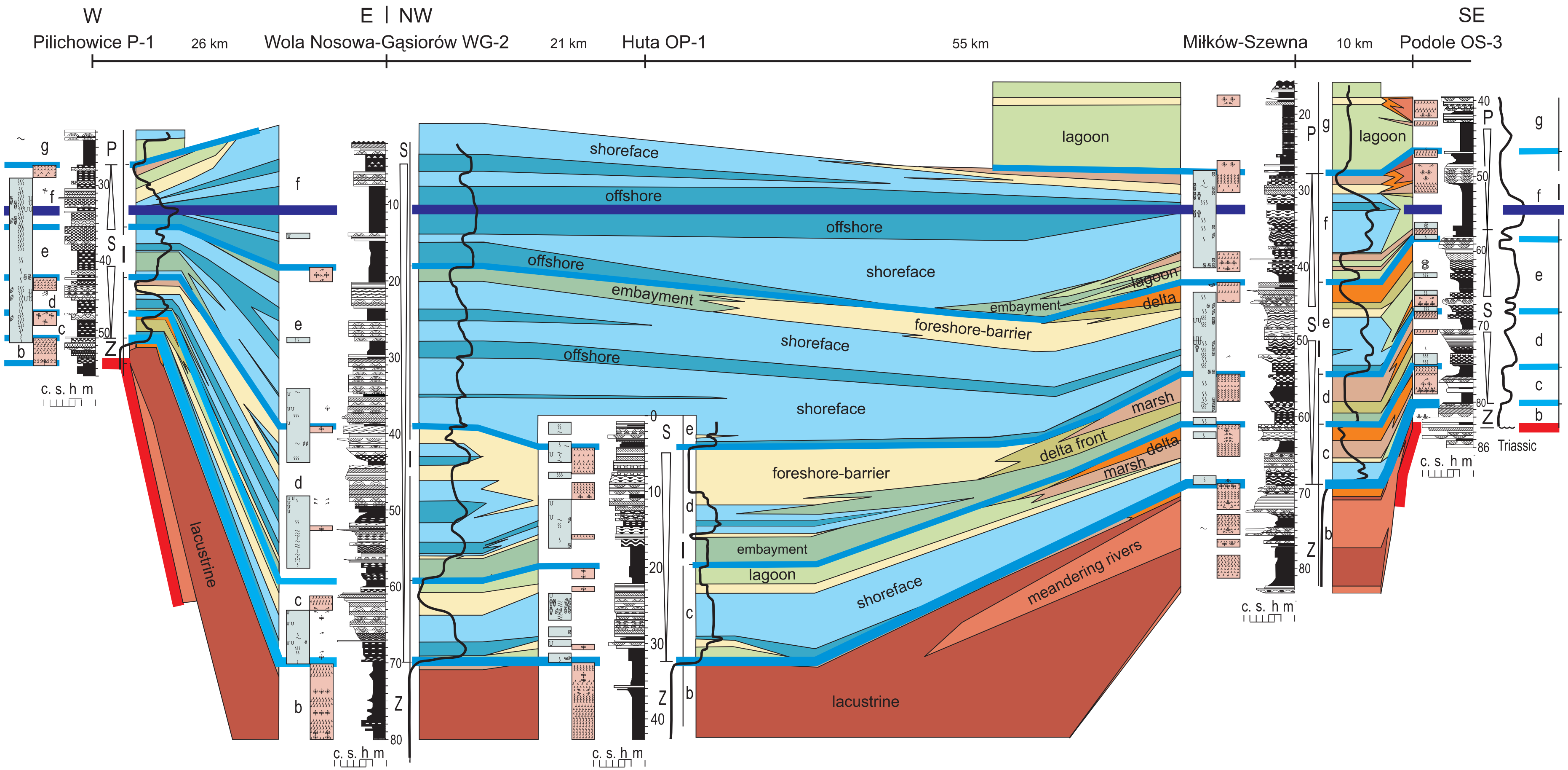


Fig. 29. Cross section of the Holy Cross Mts region showing development of depositional systems and bounding surfaces within the transgressive systems tract of depositional sequence Ib–f, Skłoby Formation

Reference horizon — maximum flooding surface of the depositional sequence I. The nearshore depositional system still dominates in the far western margin of the basin, white deltaic depositional system is prominent in the eastern margin of the basin.. This is probably caused by significant differences in river discharge and sediment supply between eastern and western margins of the basin. For explanation see Fig. 16

NEARSHORE DEPOSITIONAL SYSTEM

The shore zone, excluding deltas, comprises the relatively narrow, high-energy transitional environment that extends from the landward limit of marine processes down to fair-weather wave base, commonly at about 10 m (Fig. 15). The offshore subsystem (shallow brackish-marine shelf basin) is also included to this system, as generally the basin's depth was probably no more than about 80 m, and storm wave-base still affected the bottom (Fig. 30). Although shore zones were relatively narrow, shoreline migration over time left a record of widespread nearshore deposits (Figs. 24, 26, 29). The nearshore depositional system is primarily nourished by longshore sediment transport, which is diagnostic of the nearshore depositional system. Reworking of abandoned delta lobes or active delta margins to gather with reworking of channel-mouth deposits of small coastal plain streams was main source of sediment in the Early Jurassic basin in Poland. Additional sediment input was via residual concentration during regional coastal plain transgression and erosion of headlands (Galloway, Hobday, 1996). Concerning lithofacies, quartz sandstones are characteristic particularly in the shallow depositional subsystems. Labile components are reduced or removed by physical and chemical breakdown that accompanies wave and current recycling, and the finer fraction is winnowed, leaving well-sorted quartz arenites. The nearshore zone is discussed in whole, irrespective whether facies represent the basinward part of strandplain sand body or of a barrier-spit depositional subsystem.

Chief processes which modified the nearshore depositional subsystems of the Early Jurassic basin in Poland were waves and long-shore marine currents. The following subsystems were distinguished within nearshore depositional subsystem (compare with Figs. 15, 30):

BACKSHORE, EOLIAN DUNES AND WASHOVER FANS

This subsystem is related to the zone situated above the fair-weather range of waves. Generally, this subsystem is represented by sandstone and mudstone lithofacies on a vegetated coastal plain. The dominant process was wind reworking of subaerial coastal sands, which led to formation of eolian dunes, sometimes with buried plants and plant roots (Pl. XIII, 2, 6). During storms, washover fans were formed with sandstone, horizontally- or trough-cross bedded lithofacies.

FORESHORE DEPOSITIONAL SUBSYSTEM

Foreshore or beach face environments corresponds to the zone of wave swash. Well-sorted quartz arenite is the typical lithology. Wind can also play a role in reworking the sand. The dominant structure is planar bedding dipping gently seaward, with low-angle discordances representing adjustment of the beach to changes in wave regime or sediment supply (Clifton, 1969). Heavy minerals tend to be concentrated in discrete laminae. Storms in the foreshore zone are usually marked by erosional surfaces or graded bedding if the coarse-grained material is available (Fig. 7). Foreshore deposits are known from several outcrops (Pls. XII, 4; XIII, 2, 4, 7; XIV, 2, 6) and number of boreholes.

SHOREFACE DEPOSITIONAL SUBSYSTEM

Shoreface zone is almost continuously subjected to a complex variety of currents, which owe their origin to waves and wind (Davis, Fox, 1972). The constantly changing nature of these driving forces dictates that the currents vary in speed and direction in both space and time. In this paper, the shoreface depositional subsystem was extended by including to it the hummocky cross stratification zone and transitional, flaser- to wavy heterolithic zone (Fig. 30). Therefore, the lower, basinward limit of the shoreface depositional subsystem is identified with a range of average storm wave-base (excluding exceptionally violent storms, which can affect the offshore zone).

Upper shoreface environments corresponding to the inner surf zone are dominated by powerful onshore, offshore and long-shore currents (Clifton *et al*., 1971; Dabrio, Polo, 1981). A ridge and runnel system is a combination of a swash bar and a trough (Fig. 30). The ridge is a tabular body of sand, which is built after storms and it migrates toward the land until it welds onto the foreshore/backshore to form a berm. Therefore alongshore-directed trough cross-beds are characteristic (Pl. XII, 4) with onshore-dipping planar cross bedding deposited by ridge migration, and irregular truncation surfaces reflecting storms and rip channels (Galloway, Hobday, 1996; Pl. XIV, 6. Ridges of wave ripple crests are generally parallel to the shoreline (Dabrio, Polo, 1981), which can be used to reconstruct the local palaeoshore alignment (Pl. XIII, 4, 7). Biogenic structures are rare and they are represented almost exclusively by dwelling structures (domichnia) such as *Skolithos*, *Arenicolites* and *Monocraterion*. Storms in this zone are marked by erosional surfaces or graded bedding if the coarse material is available (Fig. 7).

The middle shoreface in tideless seas is subject to intensive wave action and associated long-shore and geostrophic rip currents, leaving a complex depositional record (Emery, Myers, 1996, their fig. 8.10). Long-shore bars are the most characteristic forms and as they move landward they produce shoreward-dipping tabular cross bed sets (Davidson-Arnott, Greenwood, 1976). Their analogues are common in the Early Jurassic sediments of Poland (Pl. XIV, 1, 2) and they are represented by tabular, landward-dipping cross-bedding sets. Presence of long-shore bars implies, that for most of the time the astronomical tides were absent or tidal range must have been within micro-tidal range, as tidal conditions are detrimal to formation of wave-built long-shore bars parallel to coastline. Bidirectional long-shore currents (usually with dominance of

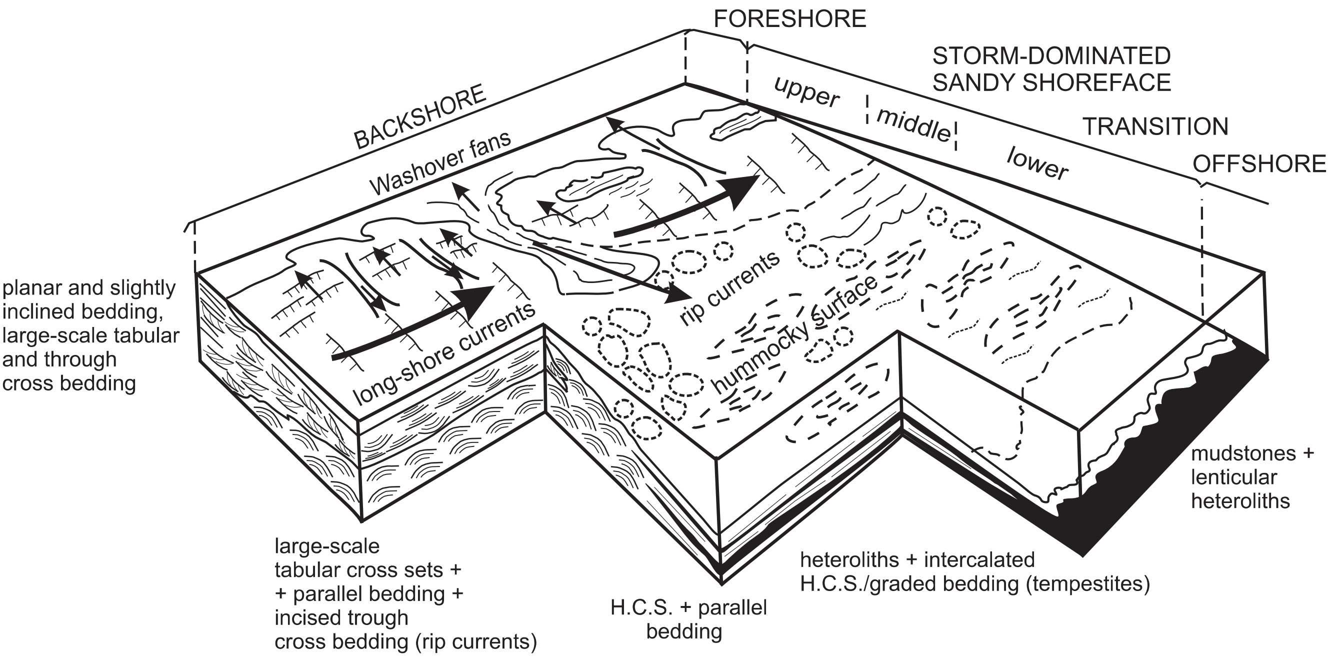


Fig. 30. Nearshore depositional system and subsystems of Early Jurassic deposits in Poland with most common lithofacies; white — sandstones, black — heteroliths and mudstones

The sketch shows offshore, shoreface, foreshore and backshore subsystems (compare with Figs. 7 and 15). Based on Handford, 1985 with changes and amendments

one direction) are also very common (Dupre, 1984; Massari, Parea, 1988). Such currents cause the greatest amount of sediment transport in the recent nearshore zones (Davis, 1978). Early Jurassic analogues with the same suite of structures indicate significant long-shore currents with unidirectional or, less frequently, bimodal, shore-prograding azimuths (Pl. XIV, 1).

Horizontal bedding, sometimes with parting lineation is common (Pls. XII, 4, 7; XIII, 1; XIV, 5). Such structures are indicative of strong currents (upper flow regime) (Allen, 1964a). One should note, that lee-side grain avalanching on ripples and dunes with low height/length ratios is not capable of producing well-defined cross-strata. Bedform migration in such cases produces “horizontal” stratification (Smith, 1971).

Trough cross-bedding sets and horizontal bedding of a scour- and fill-character occur within tabular sets or horizontally bedded sheet sandstones (Pl. XII, 7). In some cases, conglomeratic lags occur at the bottoms of the troughs and in most cases they are infilled with coarser sandy sediment. The trough axes show mostly an orientation perpendicular or slightly oblique to inferred palaeoshore direction and the currents were running toward an open basin. The sediment grading alone indicates rapid deposition from suspension, but the presence of cross-stratification in many troughs points to a deposition driven by migrating bedforms with low height/length ratios. The fining-upward textures, sharp erosional bases, and sedimentary structures within the sediments filling the “troughs” point to a rapid deposition by episodic, waning flows (Fig. 30). Storm-associated rip currents (precisely, storm surge ebb) in a shoreface environment could provide the best explanation of mechanism of deposition of these “troughs” (Ingle, 1966). Davidson-Arnott and Greenwood (1976) suggested that rip currents expand seaward of a breaker zone, which causes a sudden decrease in flow velocity, and results in the deposition of large volumes of sediment in the offshore direction (Fig. 30). Walker (1984) believes that such flows could be effective sediment transporters to a few hundred meters offshore.

In high wave energy regimes of middle shoreface zone, parallel-laminated sand is deposited under conditions of intense bottom shear (Kumar, Sanders, 1976) and may preserve low-amplitude undulations or hummocky cross-stratification (Walker, 1984). Storms in this zone are still usually marked by erosional surfaces or graded bedding if the coarse material is available (Fig. 7), but some truncated storm layers with hummocky cross stratification may appear in this zone.

Biogenic structures are dominated by dwelling structures (domichnia) such as *Skolithos*, *Arenicolites* and *Monocraterion*. Intense bioturbation can lead to obliteration of primary depositional structures (Pl. V, 5).

Lower shoreface deposits accumulate in the zone affected by average storms (Fig. 7). Storm-wave surge produces irregularly undulating surfaces of low hummocks and swales (Fig. 30; Harms *et al*., 1982). This is the zone of formation of hummocky cross-stratification — the most common type of cross bedding in the lower shoreface setting (Pls. XII, 8;. XIII, 1, 5; XIV, 2–4). Thus, hummocky cross-bedding is indicative of high-energy, storm-influenced nearshore environment situated approximately between fair-weather and storm-weather wave base (see previous chapter on lithofacies). Hummocky cross-stratification is largely restricted to very fine sand. In most cases the hummocky cross-stratification occurs in so called "amalgamated" sequences (Dott, Bourgeois, 1982), but separated cosets are also common (Pl. XII, 8). Below the hummocky cross-stratification zone, the so-called transitional zone between shoreface and offshore zone occurs. It is included by some authors to the inner shelf/offshore zone (Leckie, Krystynik, 1989; Galloway, Hobday, 1996). The proportion of sand, silt, and mud and the dominant physical and biogenic structures depend on the sediment available and the wave-energy regime. Wavy to flaser heteroliths are dominant here (Pls. III, 4, 6, 7; V, 4, 7, 8). Microhummocky cross-lamination is common (Pls. III, 4; IV, 5; V, 1, 2, 4) as well as with graded, storm-generated beds — tempestites (Dott, Bourgeois, 1982; Aigner, 1985; Fig. 7; Pl. IX, 5).

Concerning the ichnofacies, the largest population of invertebrates is commonly found just below average storm wave base, at the shoreface/offshore transition (Howard, 1978). Biogenic structures are represented by mixed dwelling-feeding structures of *Cruziana* ichnofacies (see the chapter on ichnofacies). In fully marine conditions, *Diplocraterion parallelum* structures are common in marine salinity conditions.

Palynofacies characteristics show that many sporomorphs are mechanically destroyed and other palynomacerals are reworked and dispersed (Fig. 9; Pl. VI, 3).

OFFSHORE DEPOSITIONAL SUBSYSTEM

The offshore zone extends deeper basinward from an average-storm wave base (Fig. 30). It can be identified with the inner shelf zone of an epicontinental, broad shelf type (Galloway, Hobday, 1996, their fig. 7.1A). Only strong storms affected the bottom producing lenticular bedding or lenticular lamination (Pls. III, 3, 5; IV, 1; XIV, 8) and distal storm cycles or "microturbidites" with graded bedding (Fig. 7; Pls. IV, 7; IX, 8b). Ichnofacies are represented by deposit feeders, such as *Teichichnus* (Pl. X, 1a, b), *Tuberculichnus* (Pl. X, 4) and *Chondrites* (Pl. X, 5). A "post-storm" ichnofacies may also comprise dwelling burrows *Rosselia*, which are normally typical of more shallow environment (Pl. IX, 8a, b).

Depth of the epicontinental Early Jurassic brackish marine basin can be estimated based on two methods. The first one is comparison with modern, semi-closed, epeiric, tideless, brackish-marine basins. Such analogue is the Baltic Sea (Fig. 15). Comparison of modern Baltic Sea lithofacies (Uścinowicz, 2000) with Early Jurassic lithofacies shows that muddy-heterolithic lithofacies occur below 60 m. However, results from the Baltic Sea can be biased towards coarser facies due to the reworking of relict Pleistocene deposits. Another result come from the German Bight of the North Sea (Aigner, 1985). Coastal sand passes into a sand-mud transition zone at about only 7 m depth, and the transition zone passes into a zone of shelf mud at about 15 m deep. According to Walker and Plint (1992), the fair-weather wave base (i.e. lower limit of dominant sandstone lithofacies) in modern seas generally ranges from about 5–15 m and average storm wave base is about 20 m. However, one should bear in mind that heavy storms may reach the bottom even below 150 m.

Another method is based on the approximate reconstruction of accommodation space of the basin. If it is based on the following assumptions:

— thickness of a sediment column is counted between a maximum flooding surface and deposits with plant roots, which represent emersion;

— relatively continuous sedimentation in a fairly regular progradational sequence representing highstand systems tract with relatively stable sea level is assumed;

— average compaction rate of 1.4 is accepted;

— subsidence is disregarded as insignificant due to relatively short period of time

— one obtains a maximum water depth of about 21 m in the marginal part of the Middle Hettangian basin (depositional sequence I, Gliniany Las 1, depth 63.0–78.0 m, Fig. 5 CD). It should be noted, that the sediment-loading factor cannot be accounted for, therefore the results may be somewhat exaggerated. It means that the muddy, basinal lithofacies in Early Jurassic brackish-marine basins appeared at depths 20–30 m. Probably, they were not exceeding some 40–50 m deep. Such estimations are somewhat higher than those given by Aigner (1985), but are generally in good accordance with the figures given by Walker and Plint (1992).

It should be noted that narrowness and isolation of many parts of the Early Jurassic epicontinental basins in Poland created conditions where even much lower basin depths might create hydrodynamic conditions similar to those occurring at greater depths in the shelf basins. Such relatively small and shallower "restricted brackish-marine shelf basins" were defined as "open embayments" or bights. Muddy/heterolithic facies could occur there at depth range between 10 and 20 m — similar to figures given by Aigner (1985) from the modern German Bight. Those "open embayments" differ from semi-closed embayments and lagoons in absence of apparent barriers or spits separating them from the open shelf basin. Shoreface zones of "open embayments" are usually narrower than those associated with the open shelf basins. In fact, Early Jurassic marine/brackish marine basins in Poland were similar to large, semi-closed embayments, except for the Pliensbachian marine basin in Pomerania region. It became particularly clear in Early Toarcian times, when almost the whole basin was chiefly of such character.

Palynofacies of the open brackish-marine basin (Fig. 9) show scarce palynomacerals, white, translucent AOMA (amorphous organic matter of aquatic origin) and more frequent dinoflagellate cysts (Pl. VI, 4).

MARINE BASIN — OPEN MARINE SHELF DEPOSITIONAL SYSTEM

Open marine shelf basin deposits occurred only in Early Pliensbachian and perhaps in Early Toarcian in the west part of Pomerania region and is described based on the borehole materials (Mechowo IG 1, depth 600.0–660.0 m, Fig. 31 CD; Kamień Pomorski IG 1, depth 250.0–287.0 m, Fig. 32 CD; Pl. X, 3, 6–8). With regard to hydrodynamic conditions, this depositional system is very similar to the offshore depositional subsystem described above. In the deepest parts of the basin, dark grey to brown grey mudstones and shales with pyrite, siderite and marine fauna (including ammonites) dominate. They resemble burrow-mottled silty mudstone lithofacies or moderately laminated grey mudstone lithofacies of Schieber (1999). The ichnofacies is dominated by *Chondrites* and pyritized tubes of *Palaeophycus* (Pl. X, 3, 7). At least temporarily, the bottom environment was oxygen-depleted (dysaerobic), which is evidenced by presence of *Chondrites* (Pl. X, 3). Some exceptionally heavy storms could affect the bottom, leaving distal storm cycles, improving temporarily living conditions (post-event ichnofacies) and bringing "exotic" palynofacies elements (second type of palynofacies inversion). The typical “background” palynofacies is characterised by scarce palynomacerals. White-translucent AOMA (amorphous organic matter of aquatic origin) and dinoflagellate cysts are characteristic.

Estimation of accommodation space obtained from thickness of sediments between the maximum flooding surface and subaerial deposits at the base of next depositional sequence indicates that the Early Pliensbachian marine shelf basin in Pomerania region would be some 90 m deep (assuming compaction ratio 1.6 appropriate for clays and mudstones, Mechowo IG 1, depth 573.0–628.0 m, Fig. 31 CD, depositional sequence IV, Early Pliensbachian). However, erosion at the base of overlying depostional sequence V has removed an unknown portion of sediments, thus the basin could have been deeper. Lack of conspicuous tempestites (even the distal ones) suggests that the depth of the marine shelf basin in the west part of Pomerania region in Early Pliensbachian (*ibex* Zone) might have reached 100–150 m.

TIDE-INFLUENCED SHORE ZONE DEPOSITIONAL SYSTEM

This system is discussed separately, as its share in depositional processes in Early Jurassic times in epicontinental Poland was of little significance due to the semi-closed, shallow character of the basin. However, one should bear in mind that the available data from nearshore system of the marine Pliensbachian and Early Toarcian basins are scarce and their share of tidal deposits could be more significant. As far as concerns exposures of Early Jurassic deposits in the Holy Cross Mts, neither specific vertical sequences intersected by runnels and channels (Reineck, 1972) nor other diagnostic structures such as cross strata separated by erosion surfaces with mud drapes (de Raaf, Boersma, 1971) or vertically accreted tidal bundles (Kreisa, Moiola, 1986; Tessier, Gigot, 1989; Murakoshi *et al*., 1995) have been observed. A local occurrence of “herringbone” cross stratification (Pl. XIV, 1) cannot serve as sufficient evidence. Reversed currents driven by changing wind and waves in the shoreface zone seem to provide a simpler and better explanation. So far, probable tidal deposits have been found only in the Early Pliensbachian deposits in the Wielkopolska region (Pobiedziska IGH-1 borehole — Fig. 1) and in the Late Pliensbachian heteroliths occurring in the Fore-Sudetic Monocline (Gorzów Wielkopolski IG 1 borehole — Fig. 1). These few metres thick intervals comprise both characteristic bi-directional “rhytmites” with mud drapes and frequent, regularly repeating erosional surfaces with mud clasts, and evidences of rapid shifts between erosion and sedimentation periods. *Diplocraterion paralellum* Torell dwelling structures of both pro- and retrusive character, bivalve resting tracks of *Lockeia amygdaloides* (Seilacher) and fodinichnia (deposit feeders structures) are common. It points that mesotidal influence could reach central Poland, at least in Pliensbachian times.

SEDIMENTATION AND DEPOSITIONAL SEQUENCES OF THE EPICONTINENTAL LOWER JURASSIC DEPOSITS IN THE POLISH BASIN

SEQUENCE STRATIGRAPHIC TERMINOLOGY ADOPTED IN THIS PAPER

Sequence stratigraphy may be applied in two ways, either involving detailed sequence analysis based on depositional architecture and cyclicity in the rock record (Surlyk, Ineson, 2003), or construction of age models based on the correlation with global (Haq *et al*., 1987) or at least superregional sea level charts (Hesselbo, Jenkyns, 1998; de Graciansky *et al*., 1998a, b). Both approaches have been integrated in the present work, aimed at determination of correlative significances and ages of key surfaces and derived sea level curves.

In the present work, the original definition of depositional sequence is adopted (Mitchum *et al*., 1977; Haq *et al*., 1987; Jervey, 1988; Posamentier *et al*., 1988): a depositional sequence is "a stratigraphic unit composed of relatively conformable succession of genetically related strata and bounded at its top and base by subaerial unconformities and their correlative conformities". The depositional sequence is defined in relationship to the relative sea level (base level) changes (Fig. 26). Relative sea level is understood as the sum of superregional sea level changes and tectonic subsidence (the term "eustatic" is generally avoided it the present work, due to unproven synchroneity of most sea level changes in global scale). The timing of formation of the depositional sequence boundary is generally related to the stage of base level fall. Consequently, an "Exxon approach" to sequence stratigraphy was adopted in this paper. This approach offers more advantages for the Early Jurassic materials from outcrops and boreholes (predictive, detailed models with unconformities and flooding surfaces and more reliable time framework provided by unconformities) than in the case of genetic stratigraphic sequences (Galloway, 1989). Genetic sequences do not contain predictive systems tracts and they do not account for erosion at unconformities. According to Catuneanu *et al*. (1998), the depositional sequence comprises four systems tracts (understood as a linkage of contemporaneous depositional systems) with distinct stratal stacking pattern: the transgressive systems tract (TST), which forms when sediment supply is insufficient to maintain progradation during relative sea level rise (Fig. 26); the highstand systems tract (HST) which forms, when the sedimentation rate exceeds the rate of relative sea level rise in the shoreline area ("normal regression"); the falling stage systems tract (FSST) which forms during relative fall of sea level (forced regression); the lowstand systems tract (LST) which forms during early relative rise, when the sedimentation rate exceeds the rate of relative rise in the shoreline area. The latter three systems tracts (HST, FSST and LST) form together a progradational package known as a regressive systems tract (RST) (Embry, Johannessen, 1992). Recognition of the FSST and LST is possible only in the marine portion of the basin. In shallow, shelf marginal-marine and continental Early Jurassic basins in Poland, both FSST and LST deposits are missing or strongly reduced, as the time of their formation in the marine basin was usually associated with erosion occurring landward. This means that the time equivalent of both FSST and LST systems is simply a sequence boundary, comprising both erosional and non-depositional hiatus, or they can be hypothetically represented by some of thin packages of coarse-grained alluvial deposits at the bases of TST systems tracts (within their "pre-transgression" successions). If such "packages" are present, they should be regarded as equivalents of LST or lower TST systems tracts, formed during an earliest stage of relative sea level rise. However, distinguishing between such a LST equivalent and overlying alluvial deposits commencing the TST is impossible. It led the present author to distinguishing of only two systems tracts within a depositional sequence: retrogradational TST and progradational, regressive HST. Consequently, type-1 and type-2 sequences (van Wagoner *et al*., 1988) can be recognised only tentatively, based on more or less incised character of the sequence boundary and comparison with its equivalents (Ligurian cycle, Exxon curve).

Major bounding/correlative surfaces within depositional sequences are:

— **sequence boundary** (erosional, subaerial surface), associated with hiatus.

Characteristics: superregional range, erosional/non-depositional hiatus more prominent in the landward direction, often channelised erosion cutting down into underlying sediments, sharp facies contrast (usually alluvial depositional system above the sequence boundary contact with different marginal-marine/nearshore systems below the boundary), kaolinization of the sediments underlying the sequence boundary, coarse grained sediments above the sequence boundary, sometimes sediment provenance change. Particularly important is differentiation between erosional surfaces caused by local tectonism and those representing sequence boundaries. The most important difference is their lateral extent. In case of tectonic origin, the erosional surfaces and associated coarse alluvial/deltaic sediments are local and associated with fault zones (Fig. 25). Deltaic progradation is particularly limited in space when the faults are active, as their activity create space in the hanging wall that can accommodate sediments (Figs. 24, 25). At the same time sequence boundaries and associated coarse-grained alluvial/deltaic sediments are of much wider extent (Figs. 24, 25, 26). A sequence boundary of this character (regional occurrence, marked truncation of the underlying deposits, marked lag deposits/coarse sediments above) corresponds to that described by Surlyk *et al*. (1995). Kaolinization of the underlying sediments (Pls. XII, 5, XIII, 3) is attributed to meteoritic water percolation during the non-deposition period at the sequence boundary (Pieńkowski, 1988; Brański, 1996, 1998; Ketzer *et al*., 2003).

— **transgressive surface** (ravinement surface) and its non-marine correlative.

Characteristics: superregional range, reworking of underlying sediments, sometimes dolomite and pyrite cementation (Ketzer *et al*., 2003), long-lasting transformation of depositional systems occurring above the surface (Figs. 25, 28, 29). Contrary to Catuneanu *et al*. (1998) and accordingly to Surlyk *et al*. (1995), this paper shows that recognition of the non-marine correlative of the transgressive surface can be identified within alluvial/lacustrine successions (Figs. 24–26; see previous chapter for characteristics). The high preservation of fine-grained material and the upward-fining trend suggest high and increasing rates of base level rise that eventually led to marine flooding (Figs. 24, 25). A similar characteristic of transgressive surfaces and their non-marine correlatives was given by Olsen *et al*. (1995) and Surlyk *et al*. (1995).

— **maximum flooding surface** (downlap surface) and its non-marine correlative.

Characteristics: this is the level of a superregional range which shows the most pronounced marine influence within a given sequence. It usually contains rich and diversified ichnofauna, shows maximum landward extension of marginal-marine, usually fine-grained sediments and sometimes is associated with siderite or ankerite cementation (Figs. 28, 29). The maximum flooding surface separates a retrogradational transgressive succession from progradational, regressive succession, i.e. it separates transgressive systems tract (TST) from highstand systems tract (HST).

Within TST and HST successions, parasequences are distinguished. Parasequence is commonly considered the basic building block in sequence stratigraphy. According to Van Wagoner *et al*., 1990 a parasequence is a "relatively conformable succession of genetically related beds or bedsets bounded by marine-flooding surfaces or their correlative surfaces". In this paper parasequences are understood as successions related to broader, allocyclic fluctuations of relative sea level (at least on a regional scale), not autocyclic sedimentary processes on a local scale. Therefore, not every flooding-prograding succession is regarded in this paper as a parasequence. Most local successions (or cycles), usually one to several metres thick (Figs. 16, 28), can be produced by autocyclic mechanisms (such as fluctuations in a local sediment supply). Applying an alternative interpretation, such minor-scale successions could be defined as parasequences, eventually grouped in regionally relevant sets of parasequences. However, I doubt if such approach is justified, because the mentioned above definition requires that parasequences should constitute the basic building block in sequence stratigraphy, therefore they should reflect more significant changes in the relative sea level and they should be of at least regional significance (Figs. 16, 24, 25, 28, 29). Moreover, introducing "sets of parasequences" would complicate both terminology and hierarchy, in my opinion, "sets of parasequences" are better defined as systems tracts. Assuming these arguments, the following hierarchy of sequence stratigraphic successions is applied:

— superregional **sequences** — which can be identified at a distance of hundreds to thousands of kilometres; the sequences are composed of

— regional **parasequences** — which can be traced at a distance of tens to hundreds of kilometres; in the parasequences one can distinguish numerous

— local **cycles** (successions) — produced by autocyclic processes or sedimentary events, which can be traced usually at a distance of few hundred metres to several kilometres.

In this paper, marine flooding surfaces, often represented by their correlative surfaces, are called flooding surfaces. Parasequences represent prograding, generally upward-shallowing successions beginning with flooding surfaces and ending with shallow facies, which are frequently associated with emersion and palaeosol development (plant roots; Figs. 16, 28, 29). In the Early Jurassic basin of Poland (mostly of marginal-marine character), palaeosol development processes associated with the end of progradation and parasequence development extended far to the basin. The wide range of such palaeosol horizons is a major criterion allowing differentiation between parasequences and other subordinate cycles (autocyclic successions). The Early Jurassic marginal-marine parasequences from the Polish epicontinental basin usually show a more composed lithofacies and depositional systems development (Figs. 16; 26 — type 1 parasequences; 28) and can not be described exactly in terms of simplified, "ideal" models of rapid flooding — gradual prograding, where the parasequence maximum flooding stage is practically identified with the lower parasequence's boundary (Emery, Myers, 1996, their fig. 2.24; Coe *et al*., 2003, their figs 4.5; 4.6; 8.11). These conventional models assume that deepening parts of parasequences are usually not preserved as transgressive sediments. However, careful facies analysis of the Lower Jurassic parasequences in Poland shows that in most cases deepening parts of parasequences above the clearly defined flooding surfaces are preserved as transgressive sediments (Figs. 16; 28). It is probably related to a semi-closed, shallow character of the Early Jurassic basin in Poland, which enabled a wide basinward redistribution of transgressive sediments. Consequently, one can distinguish the parasequence maximum flooding surfaces within most parasequences (Fig. 26, type 1 parasequences). The parasequence maximum flooding surface is not associated with flooding surface, as the flooding surface represents a first conspicuous transgressive impulse commencing facies back-stepping (retrogradation) at the base of parasequence, while the maximum range and depth of basin occurred later in a parasequence development (and higher in the parasequence's profile). Thus, these marginal-marine parasequences resemble rather "mini-sequences" than simple coarsening-upward, regularly prograding successions (Fig. 26, type 1 parasequences; for example see a vast majority of parasequences from the Holy Cross Mts region — Figs. 16, 28, 29 and CD — Figs. 4, 5, 18, 19, 21–23, 27). Such parasequences seem to be typical of marginal-marine settings, as distance from the open marine basin, flat palaeoslope inclination, much more dynamic changes of depositional systems and wide re-distribution of transgressive sediments delays flooding processes, making them more gradual. It should be emphasised that the more "symmetrical" and composite facies architecture of the type 1 parasequence model is well established, because it usually represents a succession between very reliable bounding surfaces, such as well-defined flooding surfaces represented by palaeosol horizons/flooding surface boundaries, often accompanied by pyrite cementation (Figs. CD — 4, 5, 18,19, 21, 23 and 28, 29; Pl. IV, 3). Lack of calcite/dolomite cementations (Ketzer *et al*., 2003) at most of these parasequence boundaries can be explained by epigenetic dissolution of carbonates, because traces of diagenetic silicate grain dissolution and pyrite cementations are common. It proves that distinguishing of "composed" parasequences is justified by their real internal lithofacies succession and they are not a mere result of misplacing of the parasequence boundaries.

One of the important practical implications of such development of marginal-marine parasequences (Fig. 26, type 1 parasequences) is that their recognition based only on wire-line logs can be doubtful. On the other hand, nearshore-marine parasequences from Pomerania region (Fig. 26, type 2 parasequences; Fig. 31 CD, depth 926.0–1105.0, parasequences I b, c, e, f, i) are often more similar to the "ideal" parasequence models with simple flooding-prograding successions (Emery, Myers, 1996; Coe *et al*., 2003). The maximum flooding stages within the parasequences are usually closer to their lower boundaries (flooding surfaces). It should be noted that deepening parts of parasequences are still preserved as transgressive sediments, although transgressions are usually marked by relatively thin sediments. Flooding surfaces are often linked to the dolomite/calcite cementation (Ketzer *et al*., 2003).

Sea level cycles (forming sequences and parasequences) occur over many time scales (Emery, Myers, 1996; Strasser, Hampson, 2002). In the present work, mainly 3rd order cycles (duration 0.5–10 million years) are distinguished. They are the foundation of sequence stratigraphy because they are often of a scale well-resolved by seismic data. Principal forcing mechanisms of such cycles include such superregional sea level changes as: glacio-eustasy (global scale), geoidal eustasy (global scale) and intra-plate stress (superregional scale). Such 3rd order cycles represent sequences and some parasequences. Most parasequences represent 4th order cycles (duration 200–500 thousands of years). Principal forcing mechanisms include: glacio-eustasy (global) and Milankovitch cyclicity–eccentricity, precession and obliquity (also global). They may be related in part to autocyclic processes within the depositional system, particularly in the marginal parts of the basin. Influence of the global 2nd order cycles (10–100 million years, caused by changes in sea-floor spreading rates and ocean-ridge volumes) can be added to some particularly characteristic and widespread bounding surfaces, related also to some truly eustatic events (Early Hettangian, Early Toarcian — Hallam, 1997). A "linear" influence of the 1st order cycles (200–400 million years — break-up of Pangaea) is also possible, but it is too long a term to be of practical use for high-resolution sequence stratigraphy.

Discussion on the nature of observed sea level changes is beyond the scope of the present work. The interpretation of eustatic changes from the rock record is a complex and controversial topic. The dilemma as to which change is really global, and which only of intra-plate, superregional scale is not resolved (for discussion see Cloetingh *et al*., 1985; Miall, 1986; 1992). However, results of modern projects, aimed at the accurate dating and correlation of sequence boundaries and other correlative surfaces in Western Europe (de Graciansky *et al*., 1998a, b; Hesselbo, Jenkyns, 1998; Dumont, 1998) offered a framework — on European scale — for sequence stratigraphy of the Early Jurassic deposits, regardless of ongoing discussion on complex nature of the sea level changes. In that respect, the Exxon curve (Haq *et al*., 1987) is useful template, calibrated also from European sections. It arranged sequences in the stratigraphic order and despite some amendments suggested by the mentioned authors of the sequence stratigraphy in Western Europe, the "Exxon curve" remains an important reference, particularly concerning the range of certain bounding/ correlative surfaces.

In this work, identification of major bounding surfaces (sequence boundaries, transgressive surfaces, maximum flooding surfaces) is built up progressively from a local to regional (Figs. 16, 25, 28, 29) and superregional scale (Fig. 26). Sedimentological analysis coupled with biostratigraphy play an important role in distinguishing of sequences in a local to regional scale (see the borehole profiles), while overall biostratigraphical controll (Fig. 2) is of a key importance for superregional correlation. An overall biostratigraphical framework shows substantially varied precision, both between the regions and in geological time. The most precise correlation based on finds of ammonites comes from Pliensbachian deposits of Pomerania region (Figs. 2, 31 CD, 32 CD). Correlations in other regions are less precise, but they still provide a reliable biostratigraphical framework (for example Fig. 5 CD, depth interval 35.0–40.0 m with guiding miospores). More precise ages assigned to some key surfaces described in this paper are largely based upon a comparison with sequence stratigraphic templates from other parts of Europe (Hesselbo, Jenkyns, 1998; de Graciansky *et al*., 1998).

EARLY JURASSIC SEDIMENTATION IN THE HOLY CROSS MTS REGION

This region plays a key role in interpreting of Early Jurassic depositional systems and depositional sequences in Poland. Data from this region are also important for identification of some major bounding surfaces (Figs. 25, 28, 29). This is the only region in Poland (with exception of one exposure near Częstochowa) where the Early Jurassic deposits may be observed on the surface. Additionally, there are many shallow, fully cored boreholes which provided excellent material for sedimentological and depositional sequence studies. Therefore, the characteristics of the Early Jurassic lithofacies, depositional systems and depositional sequences is largely based on materials coming from this region. The localization of existing exposures and boreholes is presented in the Fig. 20. Additional exposures of the Hettangian and Sinemurian deposits were described in previous work (Pieńkowski, 1980), although some no longer exist. Nineteen shallow boreholes from this region are documented herein.

DEPOSITIONAL SEQUENCE I

Sedimentation of Jurassic deposits was preceded by conspicuous erosion. Jurkiewiczowa (1967) reported buried palaeovalleys of rivers from the Przedbórz area (Fig. 20), which were cut down to 60 m into the Upper Triassic red bed deposits. On the other hand, near the depocentre (Parszów between Starachowice and Skarżysko-Kamienna and adjacent boreholes — see Fig. 20) the hiatus at the Triassic–Jurassic boundary embraces only Upper Rhaetian, as shown by palynological data (Marcinkiewicz, 1957; Orłowska-Zwolińska, 1962; Fijałkowska, 1989). The Triassic/Jurassic transition was undoubtedly connected with climatic change, as Upper Triassic deposits represent generally red beds and the lowermost Lower Jurassic deposits represent coal-bearing association. Transformation from arid to more humid climate could, however, occur over a longer period as the latest Rhaetian deposits show already features of more humid climate (Pieńkowski, 1991b; Arndorff, 1993, 1994). Analysis of palaeosols from Hettangian– Sinemurian deposits of Bornholm point to a humid subtropical climate (Arndorff, 1993), on the other hand, the xeromorphic *Hirmerella*, the dominant plant in the Early Hettangian forest community of Sołtyków (Fig. 6; Pl. XI, 4–6; Pl. XII, 1) may suggest a dry season (Reymanówna, 1991) in the earliest Jurassic climate of Poland. Forest fires are indicated by charcoal occurrences (Reymanówna, 1993). The erosion occurring at the Triassis/Jurassic boundary is identified with the lower boundary of depositional sequence I, which is very striking, as the red beds contact with the coal-bearing association. The Triassic rocks below the sequence boundary are often kaolinized (Kozydra, 1968).

Basal Lower Jurassic sediments are represented by coarse, conglomerate lithofacies, passing upwards into sandstone/conglomerate lithofacies with trough- and tabular cross bedding (Szkucin–Lipa exposures — Pl. XI, 1–3; Miłków-Szewna borehole, depth 116.0–123.0 m, Fig. 19 CD; Sołtyków Sł-2, depth 22.0–29.0 m, Fig. 6). These lithofacies represent alluvial fan and braided river depositional systems. At the edges of the basin this complex may be very thin or absent (Podole OS-3, depth 82.0–83.5 m, Fig. 18 CD). In the south-east margin of the basin, a characteristic aggradational prism of alluvial fan–braided river deposits occurs between Miłków-Szewna and Podole OS-3 boreholes (Fig. 25). It is associated with rapid decrease of thickness of the whole complex of continental deposits in the Podole OS-3 borehole. A similar situation occurs at the western edge of the basin (Pilichowice P-1 borehole, Fig. 25). Such thickness contrasts and stacked alluvial fan/braided river deposits clearly point to the activity of synsedimentary faults at the beginning of Early Jurassic sedimentation (Figs. 20, 24 A, 25). In the basin depocentre, the profile commences with meandering river depositional system (Huta OP-1 borehole, depth 185.0–190.0 m, Fig. 21 CD; Fig. 25). The coarse-grained succession commencing Early Jurassic sedimentation may represent partly LST, but this cannot be proved. As discussed above, LST and FSST systems tracts are usually associated with erosion and the beginning of sedimentation is usually associated with initial TST.

Higher up, the section is dominated by sandy-muddy lithofacies of a meandering - anastomosing river depositional system (Pls. XI, 4–7; XII, 1; Huta OP-1, depth 120.0–190.0 m, Fig. 21 CD; Miłków-Szewna, depth 71.0–116.0 m, Fig. 19 CD; Eugeniów-Korytków, depth 96.0–121.0 m Fig. 22 CD). Again, at the edges of the Holy Cross Mts region this complex thins out (Gliniany Las 2, depth 65.0–67.0 m — Fig. 4).

The meandering-anastomosing river depositional system was then abruptly replaced by mudstone/claystone/coal lithofacies with palaeosols of lacustrine-backswamp depositional system, particularly well developed in the basin depocentre (Huta OP-1, depth 32.5–120.0 m, Fig. 21 CD). This sedimentary event formed an easily identifiable boundary across the whole Holy Cross Mts region (Fig. 25). This boundary is regarded as a parasequence boundary (Ia/Ib). Interestingly, at that time deposition of lacustrine deposits expanded rapidly onto the elevated marginal areas of the basin (Miłków-Szewna, Fig. 17; Pilichowice P-1, Figs. 23 CD, 25). Such rapid change of depositional systems can be explained either by rapid increase in the subsidence in the whole Holy Cross Mts region or by rapid rise of the base level. The first possibility is unlikely, as the lacustrine depositional system extended over the edges of the basin, but its thickness is still strongly reduced in the marginal areas. Rapid base level rise is more likely explanation. Such a base level rise had a pronounced effect on sedimentation in the continental basin, as alluvial deposition is rapidly replaced by lacustrine deposition (lacustrine-flooding surface coeval with marine transgressive surface — Surlyk *et al*., 1995) and advancing transgression subsequently led to development of a transgressive surface and nearshore depositional system over lacustrine depositional system forming a "step-wise" (delayed), retrogradational, encroachment of transgression onto a continental area (Figs. 24–26; see discussion in the previous chapters). The whole alluvial fan/braided river/meandering-anastomosing river/lacustrine complex shows a general decrease in the energy of depositional environments both in space (toward the basin centre) and time (in vertical section).

Progradational features, observed in the parasequence Ib in the eastern part of the Holy Cross Mts region (Figs. 19 CD, 24, 25 — note alluvial sediments in the uppermost part of the parasequence Ib), have been probably caused by a deceleration of superregional sea level rise. This progradation cannot be explained by possible reactivation of the Ostrowiec fault, because many models suggest that widespread progradation from fault blocks cannot occur when the fault is active, as its activity creates space available for deposition. Sedimentation at the basin's edges was controlled by synsedimentary faults, but during the early stage of sedimentation of the whole continental complex, which is evidenced by sharp contrasts in thickness of sediments (Fig. 25).

The whole complex of alluvial-lacustrine, retrogradational deposits belongs to the lower part of the first Jurassic depositional sequence (depositional sequence I) and it comprises two parasequences "a" and "b" separated by a non-marine correlative of transgressive surface. Both parasequences are not younger than Hettangian (as evidenced by miospores) and they are probably of the Early Hettangian age (*planorbis* Zone). In the Pomerania region, the transgressive surface–ravinement surface occurs at the bottom of parasequence Ib (Mechowo IG 1, Fig. 31 CD; Kamień Pomorski IG 1, Fig. 32 CD). In Kamień Pomorski IG 1 the parasequence Ia is thin and it probably wedges out basinward towards the Danish Basin, where transgressive marine deposits overlie directly sequence boundary or its marine correlative conformity (Fig. 26).

All the basal continental deposits (alluvial, lacustrine and upper delta plain deposits) of depositional sequence Ia and b in the Mid-Polish Trough (including the Holy Cross Mts region) and all higher continental deposits of younger depositional sequences occurring in a continuous succession are included to the Zagaje Formation. Marine-influenced trace fossil and brackish-marine fauna (sporadic foraminifera and bivalves), reported by Karaszewski (1962), Pawłowska (1962), Jurkiewiczowa (1967) and Karaszewski and Kopik (1970) from the "Zagaje series", belong to the parasequences Ic–f (i.e. to the Skłoby Formation). Ostracodes *Darwinula* sp., reported by Karaszewski and Kopik (1970) from the alluvial deposits of parasequence Ia from Sołtyków exposure (Zagaje Formation), are regarded as non-marine, mostly fresh-water forms in Jurassic deposits of China, Israel and Scotland (Mao-Yu Xu, 1988; Rosenfeld *et al*., 1988; Hudson *et al*., 1995).

A characteristic departure of coeval non-marine correlative surface from more and more landward-diachronous transgressive surface (Figs. 24–26) leads to a separation of succession of the aggradational, lacustrine/delta plain deposits between the nonmarine correlative surface and transgressive surface itself. Parasequence Ib in the Holy Cross Mts region (upper, mostly lacustrine aggradational/progradational part of the Zagaje Formation) represents such a sedimentary succession. Similar pattern of transgression development can be observed also in other Early Jurassic depositional sequences, although in the sequence I this pattern is most conspicuous (Figs. 24, 25).

In addition to "pre-transgression" parasequences Ia and Ib, there are four subsequent parasequences within the TST above the transgressive surface: Ic, d, e, f (Figs. 4, 5, 18, 19, 21–23, 27 — CD; 28, 29; CD — 33–38). In the Holy Cross Mts region these parasequences are generally included within the Skłoby Formation (Figs. 3–5, 8, 16, 17, 28, 29). In the margins of this region (except for the western margin) the deltaic depositional system prevailed (Figs. 8, 17, 18 CD, 19 CD), while the basin centre was dominated by nearshore and barrier-lagoon depositional systems (Figs. 4, 5, 21, 27 — CD, 28). The transgressive surface of the depositional sequence I occurring at the base of parasequence Ic is commonly associated with development of barrier-lagoon depositional system in the basin centre, which slightly preceded development of transgression in the basin's margins (Fig. 24, 29). The transgressive barrier-lagoon depositional system was probably associated with detachment of beach ridges from the mainland by a rise in sea level and drowning the lower areas. The deltaic depositional system was developed particularly along the eastern and northern edge of the basin (Figs. 24, 29, 39) with characteristic joint occurrence of bivalves representing both Unionoidea and brackish-marine forms — Cardiniidae and Mytyloida. Recurrent deltaic depositional systems with coarse clastics, developing in the transgressive systems tract (Fig. 39, Id, Ie and If parasequences) along the northern edge of the basin (Zawada PA-3 borehole, depth 60.0–70.0 m — note coarse-grained sediments, Fig. 33), reflect activity of the Nowe Miasto–Iłża fault (Fig. 20). The local, spatially-limited (i.e. fault-related) extent of the coarse alluvial/deltaic sediments and associated erosional surfaces is very clear on the background of wide extent of sequence boundaries and overlying coarse sediments. Kowalczewski (2002) claimed sharp thickness contrasts in the Hettangian strata (Zagaje, Skłoby and Przysucha Ore-bearing formations) and postulated conspicuous activity of the parallel Skrzynno fault (Fig. 20) in the Hettangian times. However, his thickness measurements are erroneus (Brański, pers. comm.) and no significant thickness and facies contrasts occur across the Skrzynno fault in the Hettangian times. Apparently, the Skrzynno fault played rather a subordinate role. However, even a weak activity of this fault coupled with much higher activity of the Nowe Miasto–Iłża fault could trape coarse deltaic deposits along the NE side (footwall) of the Skrzynno fault (Pogroszyn 1 borehole, Pieńkowski, 1980). This increased accumulation rate would be associated with additional accomodation space created in a long but faint tectonic trough which was formed between the Nowe Miasto–Iłża fault (with its footwall block located to the south-west) and Skrzynno fault (with its footwall located to the north-east). When the Skrzynno fault was inactive, coarse deltaic sedimentation could reach further to south-east, i.e. to the Przysucha area (Fig. 39). In contrast to the northeastern margin of the basin, its western edge shows dominance of barrier-lagoon deposits, which was probably associated with lack of larger river mouths, and indirectly with weaker tectonic activity at this margin (Figs. 29, 39). The maximum flooding surface of the whole depositional sequence occurs within parasequence I f (Figs. 28, 29, 39) and it is associated by wide expansion of the offshore depositional subsystem. In the depocentre of sedimentary basin, offshore mudstones deposited below the storm wave-base prevail (Wola Nosowa--Gąsiorów WG-2, depth 8.0–13.0 m, Fig. 27 CD). Since the early sixties (Karaszewski, 1962) this complex, called the "sub-ore beds", was noted for its pronounced marine influence. Such a view is reinforced by the present author's studies (Pieńkowski, 1980, 1983, 1991a, 1997; Pieńkowski, Waksmundzka, 2002). These strata contain the most diversified ichnofauna in the Hettangian Holy Cross Mts region, particularly in the marginal settings (for example Miłków-Szewna borehole, depth 30.0–37.0 m, Fig. 19 CD; Pilichowice P-1, depth 31.0–35.0 m, Fig. 23 CD). The widespread mudstone/heterolithic offshore-subsystem lithofacies show that the basin of depositional sequence I was both deepest and widest at that time (Figs. 29, 39). Also palynofacies with dinoflagellate cysts and Acritarcha, including *Dapcodinium priscum* Evitt (Barski, pers. comm.), show pronounced marine influences (Gliniany Las 1, depth 75.0–78.0 m, Fig. 5 CD; Pl. VI, 4). The TST deposits are identified with the Skłoby Formation (Figs. 29, 39), except for some small parts in the Holy Cross Mts region's edge (Fig. 18 cd), where part of the parasequence If belongs to the next Przysucha Ore-bearing Formation, which is based solely on lithology and lithostratigraphical principles.

Above the maximum flooding surface the progradational, regressive HST is developed, comprising five parasequences (Ig, Ih, Ii, Ij, Ik — Figs. 34–38 CD, 40). The mentioned parasequences are generally characterised by lower energy, more shallow-water depositional systems than parasequences Ic–f. Barrier-lagoon depositional cycles dominate (Zapniów exposure, Pl. XII, 5), also fluvial-dominated deltaic cycles are common. Offshore, open basin depositional subsystem deposits are rare and limited only to the central part of the basin (Fig. 40). Particularly characteristic are lagoonal deposits, represented by sideritic clays and mudstones forming characteristic "ore-bearing" horizons. In the past, these "ore-bearing" horizons were targeted as source of iron ores (Pl. II, 4) and are presently mined for their clay resources, chiefly kaolinite-rich mudstones (for example Zapniów exposure, Pl. XII, 5). Vast marsh/swampy areas developed around lagoon coasts provided high quantities of iron. In the Holy Cross Mts region, they are usually three ore-bearing horizons pointing to three episodes of widespread development of lagoon depositional subsystem (for example Mirzec MKR borehole — Fig. 35 CD). Lagoons were broad but shallow, often associated with marsh deposits with palaeosol development (Pl. II, 4). The wave-produced structures are poorly developed due to the shallowness of the basin — wave energy was quickly dissipated and reduced by the bottom friction. In places, closer to the basin centre, connections with the open sea situated to NW were wider, which led to formation of wider embayments and migrating barriers (Zapniów exposure, Pl. XII, 5). In embayments, wave-generated structures are more common and siderite bands and palaeosols are less frequent. Marine influence is more prominent, which is evidenced by marine fauna (Pl. I, 7). On the other hand, temporarily emerged barriers provided good environment both for dinosaur penetration and preservation of their tracks, and the *Anomoepus–Moyenisauropus–Anchizauripus–Grallator* footprint association (Fig. 10) assemblage is common in many localities with barrier-lagoon/deltaic deposits representing the HST regressive deposits of depositional sequence I (Gierliński, Pieńkowski, 1999). The best-known dinosaur track locality is Gliniany Las exposure, representing the parasequence Ii. Lagoons and embayments were quickly filled in by prograding

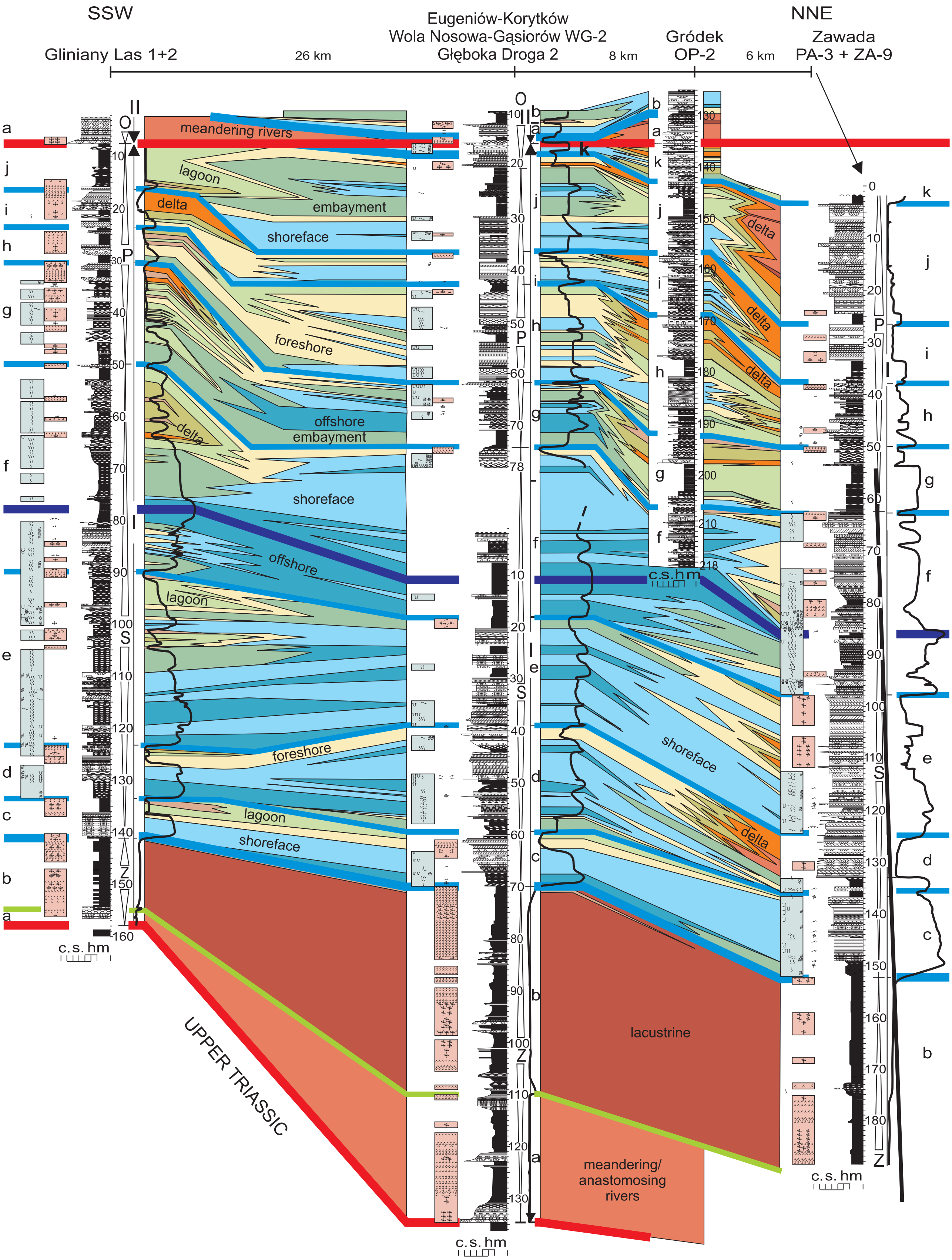


Fig. 39. Cross-section of the Holy Cross Mts region (perpendicular to those presented in the Figs. 24, 29, 40) showing development of depositional systems and bounding surfaces of the depositional sequence I

Note the transgressive systems tract (I a–f, including pre-transgression deposits) and the highstand systems tract (I f–k), separated by the maximum flooding surface. Reference level — boundary between depositional sequences I and II. Notepersistent deltaic depositional system in the NNE margin of the area studied (Zawada PA-3, ZA-9) and the dominance of nearshore depositional system in the basin's depocentre. For explanation see Fig. 16

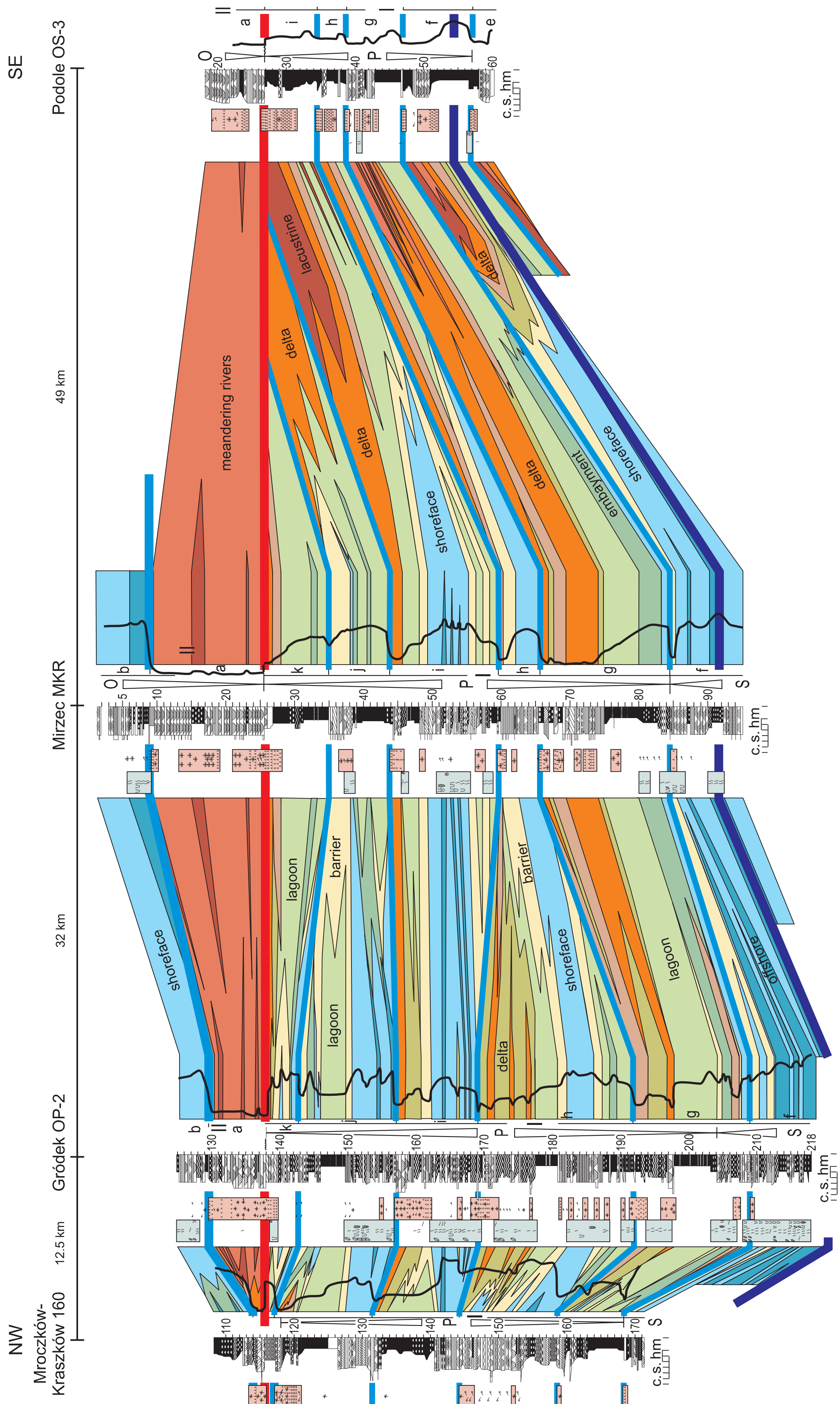


Fig. 40. Cross-section of the Holy Cross Mts region showing the high-stand systems tract of depositional sequence If–k (Przysucha Ore-bearing Formation, Upper Hettangian) and the overlying depositional sequence IIa, b (lowermost Ostrowiec Formation, lowermost Sinemurian)

Reference level — erosional boundary between depositional sequences I and II. Note dominance of lagoonal and deltaic depositional systems and erosion at the base of sequence II, particularly marked in the marginal areas (Podole OS-3 borehole). For explanation see Fig. 16

deltaic deposits in places where river mouths occurred. Lagoonal deposits are characterised by unstable boron content (Fig. 5 CD) and characteristic palynofacies (Pl. VI, 2). Development of the highstand systems tract of sequence I in the Holy Cross Mts region is presented in the Figs. 39 and 40. It shows, that major delta depositional systems reached the basin centre at the ends of Ig and Ii parasequences (Fig. 40). As it was stated many times by the present author (Pieńkowski, 1980, 1983; 1991a; 1997), contrary to previous views, the Przysucha Ore-bearing Formation represents not transgressive, but regressive, progradational characteristics. This formation occurs only in the Holy Cross Mts region (Fig. 3), thus pointing to an isolated character of this basin in the Late Hettangian times.

Depositional sequence I is the best documented of all sequences of the Early Jurassic deposits in Poland. The cross section of the whole sequence I is presented on the Fig. 39.

Depositional sequence I falls within the *Nathorstisporites hopliticus* megaspore zone (Hettangian–Early Sinemurian — Marcinkiewicz, 1971). Occurrences of pollen species *Pinuspollenites minimus* (Couper) Kemp and other characteristic miospores of the *Pinuspollenites–Trachysporites* Zone through the whole sequence indicate its Hettangian age (Pieńkowski, Waksmundzka, 2002). Occurrences of bivalves *Cardinia follini* Lungren and *Cardinia ingelensis* Troedsson are restricted only to this sequence (Fig. 2).

DEPOSITIONAL SEQUENCE II

This sequence is fully documented in Mroczków-Kraszków 160 (Fig. 36 CD), Gródek OP-2 (Fig. 38 CD) and Szydłowiec N-1 borehole (Fig. 41 CD). A cross section of the sequence is presented on Fig. 42.

The end of progradational sedimentation of highstand systems tract of the depositional sequence I (Przysucha Ore-bearing Fm.) is followed by regional erosion surface (Pl. XII, 6; Fig. 39). In places, erosion removed sediments of the underlying parasequences. In Podole OS-3 (Figs. 18 CD, 40) deposits of parasequences Ij and Ik were eroded. In Gliniany Las 1 (Fig. 5 CD) parasequence Ik is missing. Maximum erosion rate can be estimated at about 20 m. Commonly, the uppermost part of the parasequence Ik is eroded. This erosional surface is associated with a substantial fall in sea level and it forms sequence boundary as it ends progradational HST and commences the TST of next sequence (Figs. 39, 40, 42). Usually, sediments underlying the sequence boundary are kaolinized (Pl. XII, 5), which is important for the clay minerals prospecting (Kozydra, 1968; Brański 1998).

Initial sediments above the sequence boundary (Pl. XII, 6) form parasequence IIa and are represented by medium- to coarse-grained, trough cross bedded sandstone lithofacies. In places locally-derived mud clasts occur and plant detritus is abundant everywhere. This lithofacies is exposed in Zapniów exposure (Pl. XII, 6) and is also known from numerous boreholes (Figs. 5, 18, 35, 36, 37, 38 — CD and Fig. 39). Generally, the coarse-grained lithofacies with few muddy overbank deposits points to alluvial deposits representing meandering, non-anastomosing channel subsystem. Most of the cross bedded sandstone represents channel fill or point bar deposits. Overbank fines (lacustrine depositional system) are concentrated in the upper part of parasequence IIa (Szydłowiec N-1, depth 226.0–227.0 m, Fig. 41 CD). The uppermost few metres of the parasequence Ia represent lacustrine-crevasse/?delta plain deposits (Gródek OP-2 borehole, Fig. 38 CD, depth 129.5–131.5 m; Szydłowiec N-1 borehole, Fig. 41, depth 224.0–226.0 m). It indicates that the transgressive surface was preceded by development of fine-grained deposits, which reflected the rising sea level — as was the case for depositional sequence I (Fig. 11), although the thickness of these deposits in sequence II was much smaller. Alluvial or subordinately the lacustrine deposition occurred it the whole Holy Cross Mts region and development of these depositional systems represents the initial base level rise of TST, which followed the sea level fall represented by the I/II sequence boundary (Figs. 39, 40, 42).

The next parasequence IIb starts from the transgressive surface (ravinement) of depositional sequence II. Transgression was quick, because in the whole area studied facies of nearshore depositional system overlie the parasequence IIa. Parasequence IIb is composed of nearshore depositional system deposits (well-developed offshore depositional subsystem shows that the basin was periodically relatively deep) with some barrier/lagoon and embayment deposits. The parasequence is terminated by deltaic/barrier–lagoon/marsh depositional systems deposits (Fig. 42).

The next parasequence IIc commences with a flooding surface. The flooding event was powerful and quick, as the maximum flooding surface of the whole depositional sequence II is situated only a few metres above the parasequence IIc flooding surface. Grey offshore mudstones, associated with maximum flooding surface (Fig. 36 CD, depth 83.0–86.0 m; Fig. 38 CD, 107.5 m), are uniform over the large area (Fig. 42), which points to a wide extent of the basin. Also the filling of the basin was fast; shoreface and subsequent barrier-lagoon deposits form the upper part of the parasequence IIc.

The whole depositional sequence II is thin in the Holy Cross Mts region — its maximum thickness reaches some 53 m in Mroczków-Kraszków 160 borehole (Fig. 36 CD). However, the primary thickness of the depositional sequence II could be higher as the present-day thickness of the depositional sequence II can be additionally reduced by subsequent erosion at the base of depositional sequence III.

Depositional sequence II still falls within the *Nathorstisporites hopliticus* megaspore zone (Hettangian–Early Sinemurian — Marcinkiewicz, 1971). Abundant occurrences of miospore *Lycopodiumsporites semimuris* Danze-Corsin and Laveine (Pieńkowski, Waksmundzka, 2002) allow narrowing the age of this sequence to the Early Sinemurian (Dybkjær, 1988; 1991).

DEPOSITIONAL SEQUENCE III

The sequence begins with conspicuous erosion, which eroded valleys at least 10 m deep (Gródek OP-2, depth 95.5–105.0 m, Fig. 38 CD). In places, the erosion was deeper (Gajówka-Modrzew 1 borehole, Pieńkowski 1980) or shallower

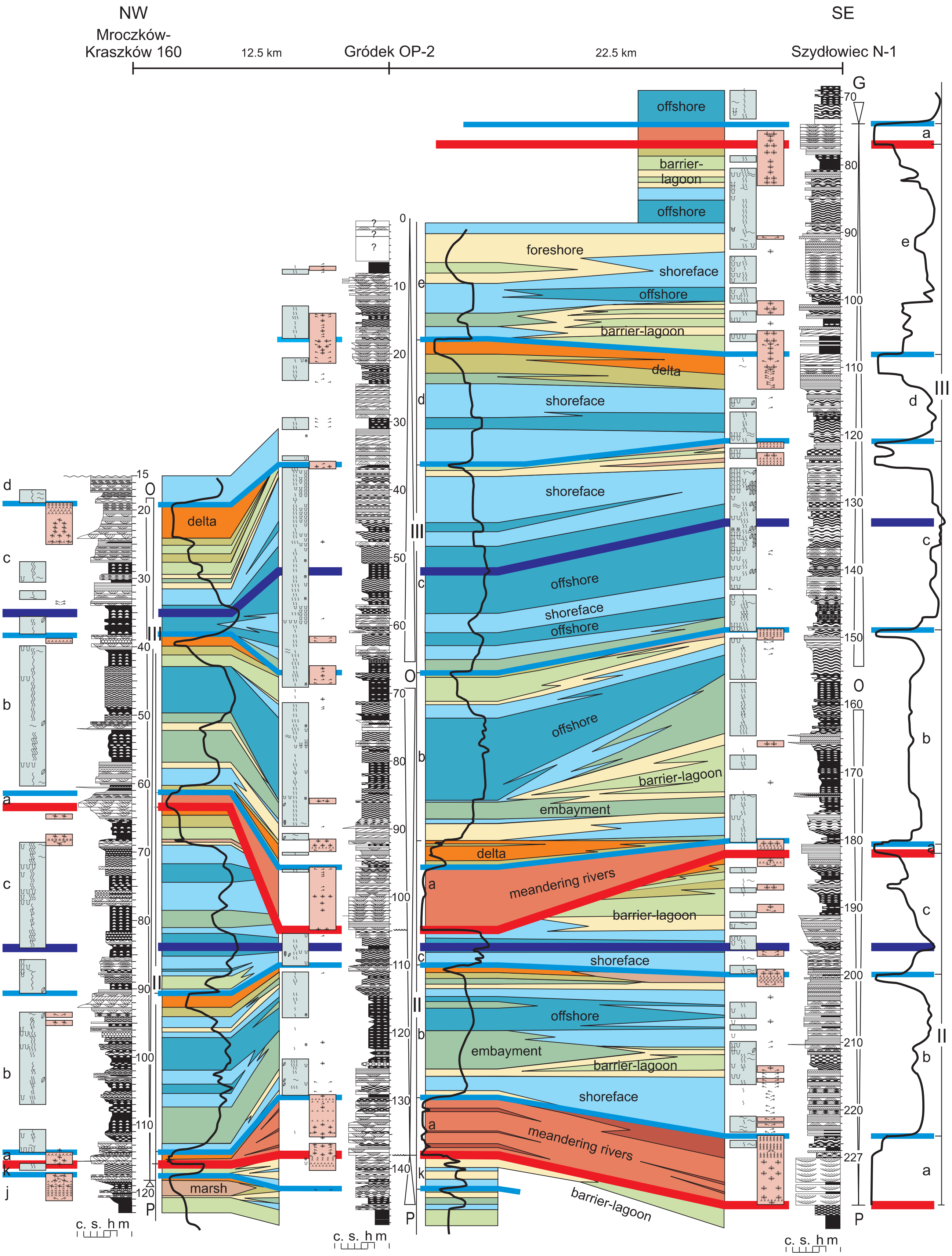


Fig. 42. Cross-section Mroczków-Kraszków 160–Gródek OP-2–Szydłowiec N-1 showing development of depositional systems and bounding surfaces in depositional sequences II and III (Sinemurian, Ostrowiec Formation)

Reference horizon — maximum flooding surface of the depositional sequence II. Note conspicuous erosion associated with sequence boundaries, particularly at the base of depositional sequence III in Gródek OP-2 borehole. For explanation see Fig. 16

(Mroczków-Kraszków 160, Fig. 36 CD; Szydłowiec N-1, Fig. 41 CD). A significant portion of underlying parasequence IIc was eroded below the palaeovalleys, e.g. in Gródek OP-2 borehole the erosion reached almost the maximum flooding surface deposits of the depositional sequence II (Fig. 42).

Development of the transgressive surface of depositional sequence III depends on the characteristics of local sedimentary conditions. In areas influenced by intense river discharge, the transgressive sediments of parasequence III b commence with a delta depositional system (Gródek OP-2, depth 95.5 m, Fig. 38 CD). In areas without river discharge or with low river discharge, the transgression immediately established a nearshore depositional system at the base of parasequence IIIb (Mroczków-Kraszków 160 and Szydłowiec N-1, Fig. 42). Relatively high sediment input associated with intensive wave reworking led to the development of barrier-lagoon depositional system — particularly evident from the Szydłowiec N-1 borehole. Maximum basin extent (maximum flooding surface) and the highest share of offshore depositional subsystem is associated with parasequence IIIc. This parasequence is largely built of heteroliths (Pl. III, 4, 5) with very abundant and diverse ichnofauna. Parasequence IIIc with basinal deposits is particularly well developed in the Gródek OP-2 (depth 48.0–57.0 m, Fig. 38 CD) and Szydłowiec N-1 borehole (depth 130.0–137.0 m, Fig. 41 CD). In Gródek OP-2 borehole (depth 36.0–37.0 m) the top of parasequence IIIc is characterised by the barrier-lagoon depositional system and emersion of the basin was very brief or did not occur. In contrast in Mroczków-Kraszków 160 borehole (Fig. 36 CD) the offshore depositional system deposits are much thinner and significant progradation of an active delta system ended the parasequence IIIc (Fig. 42). The evidence is of conspicuous bathymetric contrasts in the parasequence IIIc, that were caused by relatively significant depth of the basin at that time and by development of an active delta system from the north, which was probably associated with activity of synsedimentary faults: the Nowe Miasto–Iłża fault and possibly the Skrzynno fault (Fig. 20). Above the maximum flooding surface is the higstand systems tract composed of the upper part of parasequence IIIc and parasequences IIId and IIIe. Parasequence IIId is documented between Gródek OP-2 and Szydłowiec N-1 borehole (Fig. 42) — it is fairly uniform and it comprises nearshore deposits terminated by birds-foot delta depositional system. Parasequence IIIe shows varied development of the nearshore and barrier-lagoon depositional subsystems, with a clearly visible progradational succession in the upper part of the parasequence (Szydłowiec N-1, depth 77.0–85.0 m, Fig. 41 CD). Sequence III falls within the *Horstisporites planatus* megaspore zone (Late Sinemurian–Pliensbachian age, Fig. 3; Marcinkiewicz, 1971).

Both depositional sequences II and III form the Ostrowiec Formation. Sediments of depositional sequence III are more than twice as thick as those of sequence II (Fig. 42). Besides the Mroczków–Szydłowiec area, depositional sequences II and III are known from other outcrops (Pl. XIV, 1, 5, 7). The outcrops show development of the nearshore depositional system in both sequences.

DEPOSITIONAL SEQUENCE IV

This depositional sequence is described in details from the area between Budki 1 borehole and Jagodne 1 borehole (Figs. 20, CD — 41, 43, 44) and from the Drzewica area (Fig. 45 CD). Initial parasequence IV a is preceded by erosion associated with a sequence boundary, which was much deeper in the Jagodne 1 (depth 72.0–87.0 m, Fig. 44 CD) than in Szydłowiec N-1 and Budki 1 borehole. Alluvial deposits (meandering rivers) dominated in Jagodne and Szydłowiec, while delta system occurred in Budki area (Fig. 46).

Next parasequence IVb commences with rapid and widespread transgression, which created clear ravinement (Budki 1, depth 87.5 m, Fig. 43 CD) or quickly drowned the area (Szydłowiec N-1, depth 74.0 m, Fig. 41 CD; Jagodne 1, depth 71.8 m, Fig. 44 CD). This parasequence is generally built of offhore-shoreface deposits, but in the area around Szydłowiec, a very conspicuous and rapid delta progradation occurred (Fig. 41 CD, depth 46.0–67.0 m; Fig. 46). The well-visible lenticular lithosome of delta distributary channel and delta front subsystem rapidly wedges out at a distance of several kilometres, particularly in a SW direction. Development of this delta lobe with coarse fluvio-deltaic deposits was limited in space and was clearly associated with a short-lived rejuvenation of the bordering Nowe Miasto–Iłża fault. Coarse deltaic sediments extend beyond the Skrzynno fault, which points that this fault was probably inactive during the Early Pliensbachian times. This clearly contrasting lithosome (Szydłowiec N-1, depth 46.0–67.5 m) of isolated delta lobes (Fig 45) is named herein as the Wola Korzeniowa Member (Mb.) — see the chapter on lithostratigraphy. Development of the delta system ended deposition of parasequence IVb. The flooding surface of parasequence IVc reinstated basinal conditions in the Holy Cross Mts region and led to development of the marine offshore-shoreface depositional subsystems. In this parasequence the maximum flooding surface of the sequence IV occurs. Offshore mudstones and heteroliths near this surface show marine character associated with the appearance of marine bivalves and *Diplocraterion pallalelum* Torell (Fig. 44 CD, depth 51.5–57.0 m) indicating marine salinity. This package of sediments could be also associated with some condensation. Heterolithic deposition of the offshore depositional subsystem extended far to the east, it is recorded from Brody-Lubienia borehole (depth 276.0 m, Fig. 47 CD) and near the village of Hultajka, east of Ostrowiec Świętokrzyski, where Karaszewski and Kopik (1970) recorded presence of marine fauna (*Cardinia* sp.) in sandstone lithofacies. According to those authors, this bivalve is associated with the Lower Pliensbachian strata of maximum “marinity”. Also in the western margin of the Holy Cross Mts, marine or brackish-marine deposits with forami- nifera mark pronounced marine influences within succession identified as Lower Pliensbachian (Jurkiewiczowa, 1967). The stage of maximum marine flooding in parasequence IVc is shown in the Fig. 48: 11. The area of Szydłowiec and to lesser extent the area near Budki (Figs. 20, 46) was still affected by a waning activity of the Wola Korzeniowa delta system (Fig. 48: 11). This influence

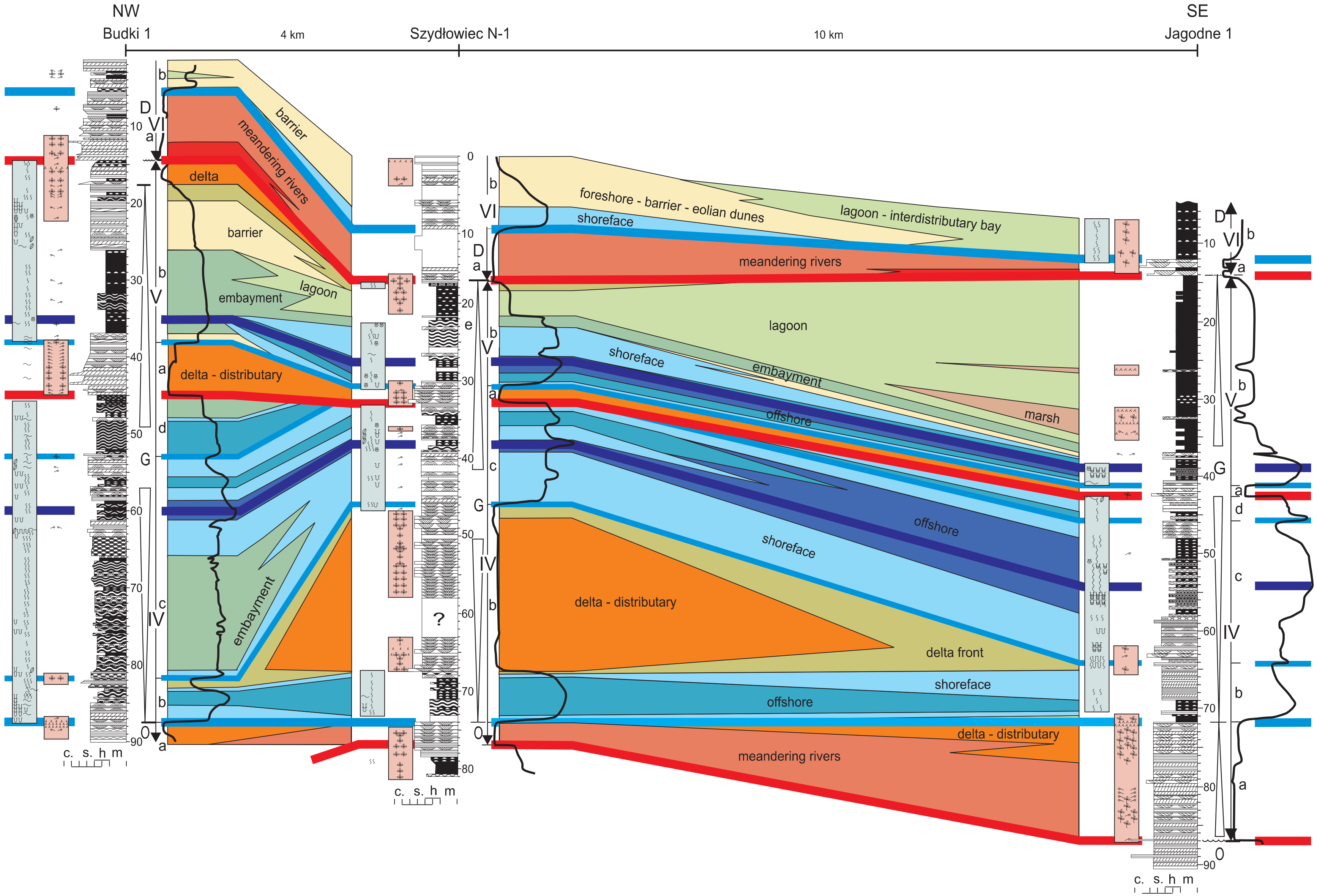


Fig. 46. Budki 1–Szydłowiec N-1–Jagodne 1 cross-section showing development of depositional systems and bounding surfaces of depositional sequences IV, V and VI (Lower Pliensbachian, Gielniów Formation and lower part of the Drzewica Formation)

Reference horizon — transgressive surface of the depositional sequence IV. Note development of the delta depositional system in depositional sequence IV in Szydłowiec N-1 borehole and migration of the delta system to the NW direction through the Pliensbachian times. For explanation see Fig. 16

is indicated by wider extension of shoreface sandstones and flaser/wavy heteroliths, representing reworked delta products, as well as by disappearance of *Diplocraterion parallelum* Torell, reflecting reduced salinity.

The strata associated with the maximum flooding surface are followed by a progradational nearshore depositional succession, but in the area studied no shallower facies than shoreface subsystem were recorded. Development of the shoreface depositional system was soon interrupted by the next flooding surface of the parasequence IVd, which briefly reinstated offshore, basinal conditions in the whole area, again soon followed by the shoreface depositional system (Fig. 46) or lagoonal-deltaic depositional system (Zychorzyn borehole, depth 96.0–100.0 m, Fig. 45 CD). In the Szydłowiec area, the whole parasequence IVd was eroded during the next forced fall of the sea level associated with the sequence IV/V boundary.

Sequence IV deposits in the Holy Cross Mts region between Budki and Jagodne are thin (about 40 m), but they are very varied in their sedimentary architecture and parasequence development. This sequence marked the most pronounced marine influence in this region (Figs. 46, 48: 11).

Outcrops of depositional sequence IV are rare and dispersed over the whole Holy Cross Mts region. Twenty-thirty years ago they were more outcrops, also around the Gielniów area, which gave the name to the Gielniów Formation. One illustrated outcrop documents the shoreface depositional subsystem (Pl. XIII, 1), probably of parasequence IVd. The sequence IV deposits still falls within *Horstisporites planatus* megaspore zone (Late Sinemurian–Pliensbachian age, Fig. 2; Marcinkiewicz, 1971).

DEPOSITIONAL SEQUENCE V

Besides Drzewica area (Fig. 45 CD) and Budki–Szydłowiec–Jagodne area (Fig. 46), this sequence is also known from the Brody-Lubienia borehole (Fig. 47 CD). This borehole is situated in the eastern part of the Holy Cross Mts region (Fig. 20) and its profile gives an insight into development of Pliensbachian deposits in the marginal parts of this basin.

Beginning of deposition of the sequence V is again associated with widespread sea level fall associated with subaerial erosion at the IV/V sequence boundary. Erosion caused by the sea level fall removed deposits of parasequence IVd in the Szydłowiec area (Fig. 46). On the other hand, erosion in the Drzewica area (Zychorzyn borehole, depth 96.1 m, Fig. 45 CD) is less conspicuous. The erosional, regressive period must have been quickly followed by transgression, as the overlying deposits are generally thin and represent not alluvial, but delta-distributary depositional subsystem (Zychorzyn, depth 94.0–96.1 m, Fig. 45 CD). Around the Budki area, sediments of the delta depositional system were slightly thicker. In Brody-Lubienia borehole (depth 265.0–270.0 m, Fig. 47 CD), an alluvial-meandering channel deposition system developed. Distributary facies are covered by the transgressive surface of sequence V. The rapid transgression quickly reinstated marine sedimentation (Zychorzyn borehole, depth interval 86.0–94.0 m with rich and diversified trace fossils, Fig. 45 CD). Some barrier-lagoonal deposits occurred around the Budki area and in Brody-Lubienia (depth 258.0–264.0 m, Fig. 47 CD). Transgressive systems tract deposits are very thin (except for Zychorzyn borehole) and the sequence V maximum flooding surface is situated several metres above the transgressive surface in the whole Holy Cross Mts region. The maximum flooding sediments (Szydłowiec N-1, depth 29.0 m, Fig. 41 CD) contain relatively rich and diversified marine bivalves such as *Pleuromya forchhammeri* Lund, *Nuculana* (*Dactryomya*) *zieteni* Brauns, *Pronoella* (cf. *elongata* Cox), which tend to point to the Pliensbachian age (Kopik, 1962; 1964). In Zychorzyn (depth 86.0 m) and Jagodne 1 borehole (depth 39.0–40.0 m), the maximum flooding sediments contain *Diplocraterion parallelum* Torell, pointing to marine salinity. On the other hand, the maximum flooding surface deposits in Budki 1 borehole (depth 35.0 m, Fig. 43 CD) and in Brody-Lubienia borehole (depth 260.0 m, Fig. 47 CD) are developed in embayment-lagoon facies. Lateral replacement of marine facies by embayment/deltaic facies in sequences IV and V along the Jagodne–Szydłowiec–Budki cross section clearly points to a shifting fluvial discharge, which was continuously moving along the Nowe Miasto–Iłża fault to the NE direction during the Early Pliensbachian times. Above the maximum flooding surface, continuous regression of parasequence Vb led to the development of barrier-lagoon depositional system topped by delta depositional system (Fig. 46). Particularly thick lagoonal deposits (connected with a bigger accommodation space in an isolated embayment/lagoon?) occur in the Jagodne 1 borehole (depth 14.2–37.0 m, Fig. 44 CD). In the area between Budki and Jagodne (Fig. 46), only two parasequences — Va and Vb can be distinguished. Depositional sequence V is generally thin in this area. This is caused by deep erosion at the base of next sequence VI, which is particularly visible near Szydłowiec N-1 (Figs. 41 CD, 46 — the total thickness of depositional sequence V there is only 16 m). Reduced primary thickness of the sequence V in this area could be also associated with locally lower subsidence rate caused by local tectonics. Further to the NW (Zychorzyn borehole, depth 27.0–94.0 m, Fig. 45 CD), the depositional sequence V is substantially thicker (67 m) and three superimposed parase- quences: Vc, Vd and Ve belonging to the HST are distinguished in this area. Sedimentation of these parasequences is dominated by nearshore depositional systems, with relatively thick barrier-lagoon deposits overlying the flooding surface of the parasequence Vc (Fig. 46). Also in the Brody-Lubienia borehole deposits of the sequence V are thicker (43 m), probably due to increased subsidence rate, similarly as it was in the Zychorzyn area. In Brody-Lubienia, parasequence Ve does not occur. Prarasequences Vc and Vd are developed by a delta depositional system.

Exposures of the depositional sequence V are quite numerous, although they are scattered around a large area. The biggest exposure is in an operating quarry near Bielowice (Fig. 20). It exhibits a high-energy shoreface depositional subsystem with horizontal bedding, hummocky cross bedding and rip channel scour-and-fill structures (Pl. XII, 7). The trace fossils assemblage is represented by dwelling structures (*Monocraterion* — Pl. VIII, 6, *Arenicolites* and *Skolithos*) and resting tracks *Lockeia amygdaloides*

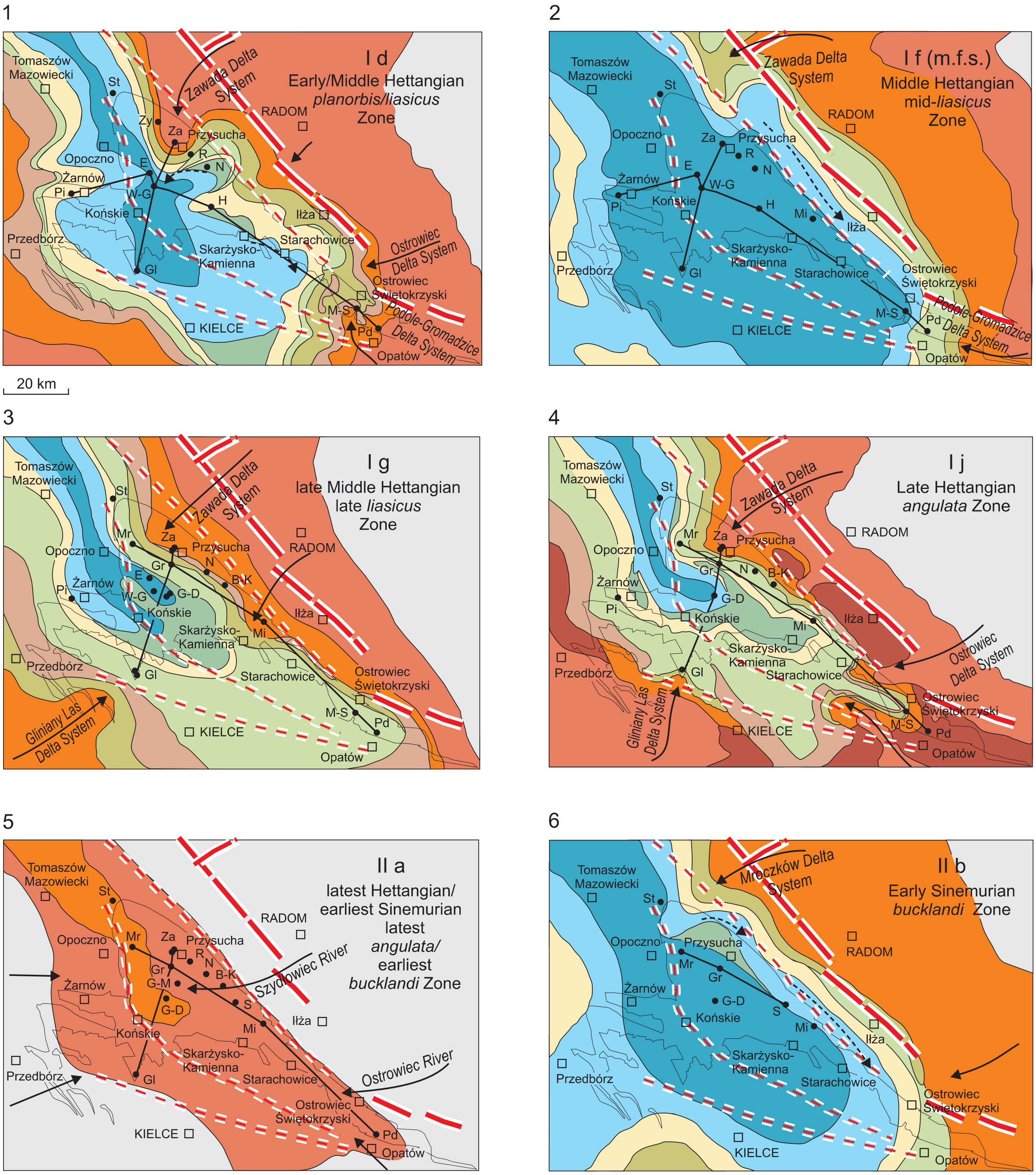
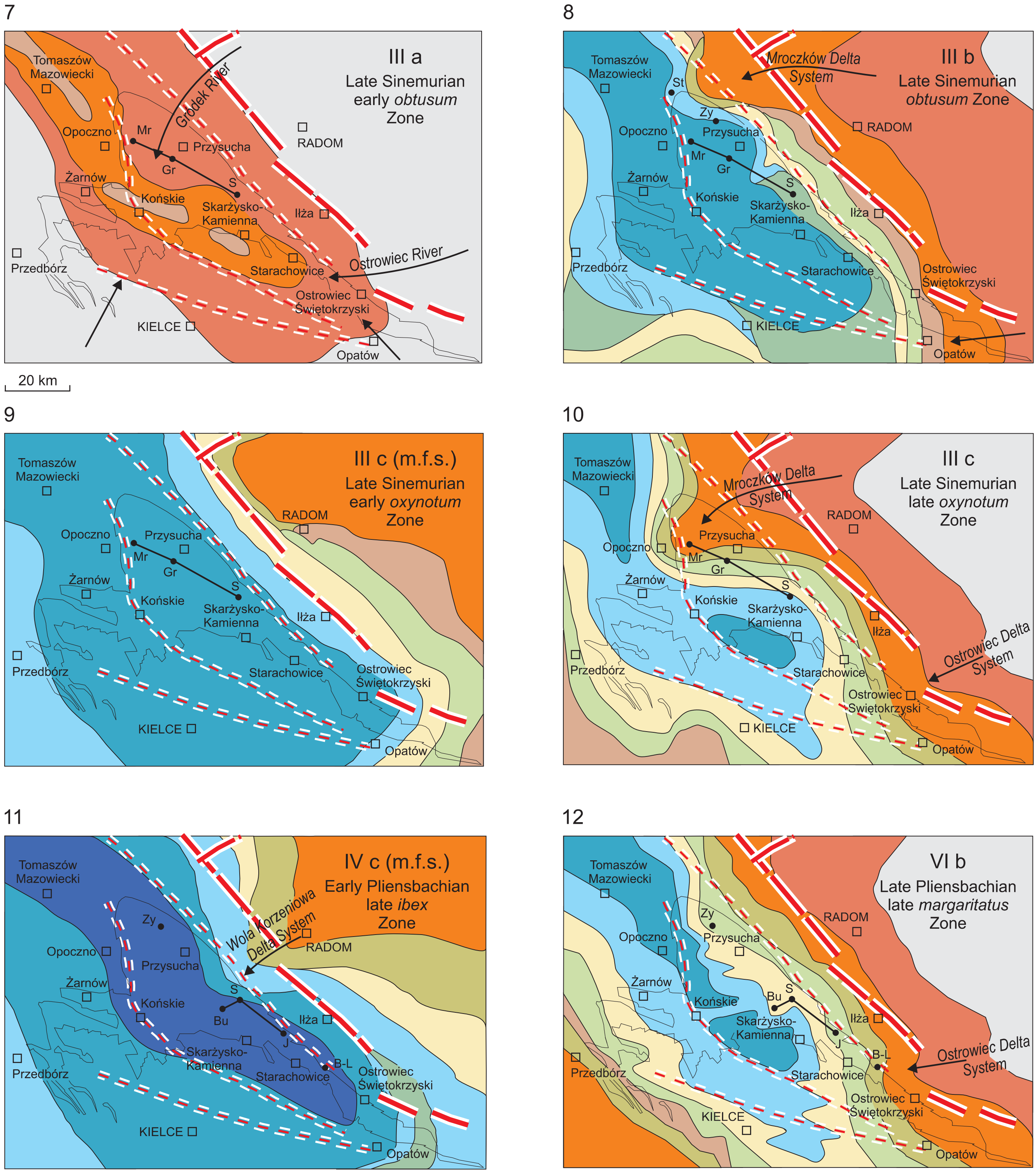


Fig. 48. Spatial development of depositional systems in the Holy Cross Mts region

Note recurrent expanding and shrinking stages of the basin caused by the sea level changes. Note that activity of syn-sedimentary faults (particularly the Nowe cies/sequence development in the earliest Hettangian times are presented in the Fig. 24 (See explanation Figs. 16, 20, 24)



in the Hettangian, Sinemurian and Pliensbachian times

Miasto–Iłża Fault) controlled spatially limited alluvial/deltaic deposition along the NW boundary of the Mid-Polish Trough. Three additional maps showing fa-

(Seilacher) — Pl. IX, 7. Another large, partly abandoned exposure is Skrzynno near Przysucha. This exposure again shows a shoreface depositional subsystem with hummocky cross stratification (Pl. XII, 8) and large-scale tabular cross bedding set — the product of onshore migration of nearshore bars.

The age of the depositional sequence V deposits falls within *Horstisporites planatus* megaspore zone (Late Sinemurian–Pliensbachian age, Fig. 2; Marcinkiewicz, 1971). The bivalves found in this sequence (*Pleuromya forchhammeri* Lund, *Nuculana* (*Dactryomya*) *zieteni* (Brauns), *Pronoella* (cf. *elongata* Cox) point to the Early Pliensbachian age (Kopik, 1962, 1964). Sequence V deposits belong to the upper part of Gielniów Formation, but in Brody-Lubienia borehole, due to the facies changes, they form the lower part of Drzewica Formation.

DEPOSITIONAL SEQUENCE VI

This depositional sequence rests on an erosional surface of exceptional range and scale. An erosional hiatus is also significant. Only the Triassic/Jurassic erosion was probably of a similar scale in Early Jurassic times in the Mid-Polish Trough. In the more marginal parts of the Holy Cross Mts region three parasequences of sequence V were eroded away. In places, the scale of that erosion can be estimated at about 30–40 m. Coarse-grained sediments occur above the sequence boundary (Fig. 46) in the Jagodne 1 borehole (depth 14.0 m, Fig. 44 CD) — very large mud clasts are characteristic, which points to intensive erosion of the underlying lagoonal sediments. Nearer the basin centre (Zychorzyn borehole, depth 27.0 m, Fig. 45 CD) erosion was probably on a lesser scale, but the presence of mud clasts at the bottom of the parasequence VI a again points to erosion of underlying muddy sediments.

Sediments which overlie the erosional sequence boundary (parasequence VIa) are uniformly represented by coarse alluvial deposits. As sandstone lithofacies with trough cross bedding dominate and overbank fines are preserved in some cycles, the depositional system is generally interpreted as meandering river. However, this system must have been characterised by conspicuous share of bed load transport. It is possible that the lower portions of coarse-grained alluvial package, particularly in Budki 1 borehole, where large scale tabular cross bedding sets dominate and quartz pebbles occur (depth 12.0–14.5 m, Fig. 43 CD), can represent low-sinuosity braided channels.

Transgression was associated with ravinement and foreshore/shoreface/barrier deposits (Szydłowiec N-1, depth 10.0 m, Fig. 41; Budki 1, depth 4.7 m, Fig. 43 CD) or lagoonal deposits (Jagodne 1, depth 5.0–12.0 m, Fig. 44 CD; Zychorzyn, depth 19.0–23.0 m, Fig. 45 CD). Transgressive facies of this character is typical of rapid drowning of the palaeorelief with alluvial valleys and coastal plains, resulting in embayed coastline with detached beach/barrier ridges (Boyd *et al*., 1992). Overlying deposits represent further transgressive facies (TST) — Zychorzyn borehole, depth 0.0–14.5m. Here the succession developed in nearshore depositional system with extensive shoreface deposits. This points to lasting equilibrium between sea level, subsidence and a relatively high rate of sediment supply. The maximum flooding surface of the depositional sequence VI occurs in the middle part of parasequence VIb (Zychorzyn, depth 4.2 m). These TST–HST transitional deposits are represented by very well sorted sandstone lithofacies with hummocky cross stratification, horizontal bedding and tabular cross bedding. They are known as Szydłowiec sandstones, praised for their building properties since the medieval times. These sandstones occur in the Szydłowiec area (Pl. XIII, 2–7), specifically in the lower part of the Szydłowiec and Śmiłów exposure. Higher up in the sequence, a regressive trend associated with HST is developed in the eolian dune depositional subsystem (Pl. XIII, 2) or barrier-lagoon depositional system (Pl. XIII, 3–7). The Śmiłów exposure shows well developed barrier form with preserved seaward-dipping clinoforms (Pl. XIII, 7) and barrier crest eolian deposits with plants buried in whole (Pl. II, 6) and dinosaur footprints, covered by lagoonal mudstones with plant roots (Pl. XIII, 3, 4, 7).

In the more marginal area, parasequence VIb is developed as partly reworked deltaic deposits (Brody-Lubienia borehole, depth 207.0–225.0 m, Fig. 47 CD). Here, the sequence VI maximum flooding surface occurs in the lower part of the VIb parasequence and consequently the TST deposits are reduced only to a few metres. The palaeogeographical map showing depositional systems of parasequence VIb is shown in Fig. 48: 12.

Generally, depositional sequence VI is thin (about 30–40 metres in Zychorzyn, Fig. 45 CD — it is only inferred primary thickness, as the upper surface is unknown), and it is precisely 20.5 m thick in Brody-Lubienia borehole (Fig. 47 CD). Development of this sequence reflects rapid sea level changes — from low stand at the sequence V/VI boundary to rapid sea level rise afterwards.

Depositional sequence VI deposits falls within *Horstisporites planatus* megaspore zone (Late Sinemurian–Pliensbachian age, Fig. 2; Marcinkiewicz, 1971). As the underlying sequence V is of an Early Pliensbachian age (bivalves finds), the sequence VI is of the early Late Pliensbachian age. This sequence belongs to the Drzewica Formation.

DEPOSITIONAL SEQUENCE VII

Depositional sequence VII in the Holy Cross Mts region is known from the marginal part of the basin in the Brody-Lubienia borehole (190.0–207.0 m, Fig. 47 CD). Its lower, alluvial portion is exposed also at Śmiłów (Pl. XIII, 3, 4, 7). The Śmiłów exposure exhibits sequence VI/VII boundary, which is rather flat, without conspicuous channelised erosional features (Pl. XIII, 3). It shows that the sea level fall was not so significant, as it was in the base of the previous sequence. The transgressive surface of the depositional sequence VII in the Holy Cross Mts region shows a rise of sea level and quick drowning of the whole area. This drowning was preceded by delta system/marsh subsystem development (Brody-Lubienia, depth 194.5–195.5 m). The resulting retrogradational succession can be compared with the pattern presented on Fig. 12. Overlying nearshore depositional system sediments indicate, that the amplitude of this transgression was quite high — in the Brody-Lubienia area (Fig. 47 CD) it was surpassed only by the transgression of Early Pliensbachian times (depositional sequence IV). The primary thickness of the depositional sequence VII was certainly higher than the present thickness of 16 m, but the depth of subsequent erosion at the base of depositional sequence VIII is unknown.

Depositional sequence VII deposits still falls within *Horstisporites planatus* megaspore zone (Late Sinemurian–Pliensbachian age, Fig. 2; Marcinkiewicz, 1971). This sequence belongs to the Drzewica Formation and is likely of a latest Pliensbachian age.

DEPOSITIONAL SEQUENCE VIII

At present time, this sequence in the Holy Cross Mts region is known only from the Brody-Lubienia borehole (101.5–191.0 m, Fig. 47 CD). Previously described exposures and borehole cores (Karaszewski, 1962; Jurkiewiczowa, 1967) are no longer accessible. The erosional surface of the sequence boundary is marked by thin layer with quartz pebbles. Erosion at the sequence boundary could be significant (an unknown portion of underlying deposits of the parasequence VII was removed prior to sedimentation of sequence VIII). Initial sedimentation of the parasequence VIII proceeded within alluvial — meandering river depositional system (Brody-Lubienia, depth 189.6–191.2 m).

The rest of the overlying deposits of parasequence VIII are represented by a delta depositional system with three delta-prograding cycles (autocyclic successions), each ending with deposition in a distributary channel subsystem. This package (Brody-Lubienia, depth 181.5–189.6 m) clearly represents a “pre-transgression” succession (compare with Fig. 26) preceding generation of the transgressive surface and associated with rising relative sea level. The transgressive surface occurs at a depth of 181.5 m. The initial stage of transgression was associated with a barrier-lagoon depositional system (175.0–181.5 m). A nearshore depositional system developed above. Around a depth of 170.0 m and higher up, between 159.0 and 162.0 m, numerous *Diplocraterion parallelum* structures indicate a marine salinity. The sideritic clay layer, occurring at the depth 165 m, is interpreted as the maximum flooding surface of the depositional sequence VIII. Basinal deposits are developed as green-grey mudstones and lenticular — wavy heteroliths with microhummocky cross stratification. Most of the silty-sandy intercalations represent distal storm events.

The succession between 156.0 m and the maximum flooding surface at 165.0 m is coarsening-upward and regressive, topped by 3 metres of shoreface-foreshore deposits with some drifted plant fossils, terminated with palaeosol horizon with plant roots. Interestingly, *Diplocraterion parallelum* Torell occurs through nearly the whole succession, proving that salinity was quite stable and the succession is not associated with any delta influx, but rather with gradual shallowing of the whole basin. The gradual character of this shallowing associated with the HST allows an estimation of the accommodation space and consequently Holy Cross Mts region’s depth at its maximum is $9 \times 1,6$ (estimated compaction ratio) = 14,4 m. This means that the basin, though of nearly fully marine character, was shallow. It may be defined as broad, shallow marine embayment.

The next parasequence (VIIIc) starts with a flooding surface overlain by basinal heteroliths with *Diplocraterion parallelum* Torell. The basinal deposits are thin (153.5–156.0 m) and quickly pass into deposits of a very shallow lagoonal-marsh depositional subsystem with green-dark grey-reddish mudstones, claystones and heteroliths with phyllopods, numerous plant roots, palaeosol horizons and desiccation cracks. Sideritic nodules and bands and coaly clays are common. The action of waves created wave ripples and silty-sandy components of heteroliths. The shallow lagoonal/marshy basin of the parasequence VIIIc was quickly filled in by deltaic deposits ending the parasequence VIIIb (depth 124.0–134.0 m). Analysis of fully-developed cycles (depth 152.0–156.0 m; 142.0–144.0 m) topped by palaeosol shows that the lagoon was of maximum about 6 m deep assuming compaction rate of 1.6.

The succeeding parasequences VIIId and VIIIe represent continuing lagoonal sedimentation in a similar, maybe slightly deeper, basin. The characteristic green-grey colour coming from chlorite is replaced by grey-brownish colours. Plant fossils are abundant but some trace fossils also occur.

General remarks on the basins in which the depositional sequence VIII was deposited can be summarised as follows: the basins were broad, shallow to very shallow, frequently emerged with subsequent development of a vegetation and high water-table palaeosols.

Depositional sequence VIII deposits falls within the *Paxillitriletes phyllicus* megaspore zone (Toarcian age, Fig. 2; Marcinkiewicz, 1971). This sequence is assigned an Early–Middle Toarcian age and it belongs to characteristic (”green mudstone-bearing”) Ciechocinek Formation.

DEPOSITIONAL SEQUENCES IX AND X

Similarly to depositional sequences VII and VIII, the uppermost Early Jurassic sequences IX and X in the Holy Cross Mts region are known principally from the Brody-Lubienia borehole (Fig. 47 CD). Besides that borehole, the deposits assigned to these uppermost sequences occur in small, isolated outcrops around Brody-Lubienia and in the westernmost part of the Holy Cross Mts region (Idzikowice near Opoczno, alluvial, dinosaur track bearing deposits — Pl. VII, 2).

These sequences are considered together, as they represent uniform, alluvial-deltaic depositional systems. Depositional sequence IX commences with greyish-brownish sandy deposits. In the lowermost part of the parasequence above the sequence boundary the core is poorly preserved, but the rest of the parasequence IX a shows features typical of alluvial, anastomosing river or delta plain depositional systems with a prominent share of type 2 (progradational) crevasse deposits (Farrell, 2001). This indicates a “pre-transgression” backstepping of the sedimentary succession prior to the transgressive surface at the depth 71.0 m (Fig. 26). In the lower parts of parasequences IXb and IXc some features of deltaic depositional system are present. The rest of parasequences IXb and IXc show typical fluvial (deltaic-distributary/alluvial) character. Thenon-marine correlative surface of the maximum flooding surface is tentatively placed at a depth of 67.0 m, within interdistributary-lagoon facies with less frequent plant remains.

Conspicuous erosion at the depth 42.5 m marks the beginning of the last Early Jurassic depositional sequence X. Erosion is marked by conglomerate lag composed of mud clasts and large wood fragments. The overlying 6 m thick trough cross bedded, fining-upwards sandstone package is characterised by very abundant drifted plant fossils (including large wood fragments) and plant detritus. It represents a laterally-migrating channel fill or point bar deposits (meandering river depositional system) and it is identified with parasequence Xa.

Overlying parasequences Xb, Xc and Xd represent various delta plain depositional system and alluvial (meandering-anastomosing river) facies. These sediments are characterised by very abundant plant remains. Flooding surfaces were tentatively distinguished on the horizons with trace fossils (fodinichnia).

The age of the depositional sequence IX and X deposits falls within Paxillitriletes phyllicus megaspore zone (Toarcian age, Fig. 2; Marcinkiewicz, 1971), therefore they are of the Middle–Late Toarcian age. The uppermost erosional surface (Fig. 47 CD, depth 6.7 m) can mark the sequence boundary and beginning of the next depositional sequence, representing already Middle Jurassic age. It is also possible that the lowermost part of this succession is still of latest Toarcian age.

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The presented development of the Early Jurassic sedimentary basin in the Holy Cross Mts gives some hints concerning development of the whole Early Jurassic basin in Poland as the Holy Cross Mts region is located still in the Mid-Polish Trough. The possibility of combining materials from the exposures and from the boreholes is of great significance for understanding the depositional systems and depositional sequence development. The preceding analysis allows presentation of palaeogeographical evolution for the Holy Cross Mts area. Three maps are shown in Fig. 24 and ten maps are presented in Fig 48, showing the "time-tuned" palaeogeography of the Holy Cross Mts region. The maps were constructed based on analysis of coeval depositional systems at chosen "time horizons" inferred from correlative bounding surfaces. Each map is constructed based on a given "time line" linking certain parasequences distinguished in profiles (see cross sections presented on Figs. 24, 25, 28, 29, 39, 40, 42, 46). The age was inferred from biostratigraphical data (Fig. 2) and correlation to the Pomerania region (Figs. 26, 31 CD, 32 CD), Danish Basin (Nielsen, 2003) and thus, with the curve presented by Hesselbo and Jenkyns (1998), Exxon curve (Haq *et al*. 1987) and time scale (Gradstein *et al*, 1995). The maps show the basin expanding and shrinking in response to superregional sea level changes and modified by local tectonics (particularly Nowe Miasto–Iłża Fault, which was active for long periods during sedimentation — for example see Figs. 39, 46, 48).

EARLY JURASSIC SEDIMENTATION IN THE CZĘSTOCHOWA REGION

In this region, Early Jurassic deposits are described based on eleven shallow, fully cored boreholes (Fig. 49). Early Jurassic sediments are strongly reduced — Hettangian and Sinemurian sediments are missing and Pliensbachian and Toarcian sediments show reduced thickness. This is due to the position of the Częstochowa region, which is far beyond the Mid-Polish Trough (Fig. 1). Depositional systems and depositional sequences are presented in borehole profiles (CD — Figs. 50–54, 56–60), in two cross section (Figs. 55, 61) and on four palaeogeographical maps (Fig. 62).

DEPOSITIONAL SEQUENCE IV

Pliensbachian deposits in the Częstochowa region rest on erosional surface, which represents a significant hiatus embracing at least the latest Triassic (Rhaetian — Bilan, 1976), Hettangian and Sinemurian. Existence of older Jurassic deposits in this region was debated in previous works (for summarising comments see Pieńkowski, 1997; Kopik, 1998). I would like to reiterate my previous view (Pieńkowski, 1997) that alternately depositional — erosional periods occurred in Hettangian–Sinemurian times in the Częstochowa region. Following the rules of sequence stratigraphy and extending the periods of basin expansion in the Holy Cross Mts region on the Częstochowa region, one can conclude that the periods with sedimentation coincided particularly with Middle Hettangian (mid-*liasicus* Zone), Early Sinemurian (mid-*semicostatum* Zone) and mid-Late Sinemurian (earliest *oxynotum* Zone). Between these periods, subsequent erosion stages particularly those of the latest Hettangian (latest *angulata* Zone), Late Sinemurian (*turneri*/*obtusum* Zone transition), latest Sinemurian (mid-*raricostatum* Zone) could have removed previously deposited sediments. However, it is possible that some isolated remnants of the Hettangian–Sinemurian deposits could be preserved, particularly in palaeomorphological depressions such as palaeovalleys. I have not found them, but some microfloristic finds (Rogalska, 1962) may point to their isolated existence. Deczkowski (1967) assigned basal deposits of the "Kalisz series" and overlying "Olewin series" (totally some seventy-two m thick) in the Wieluń 1-KW borehole (for location see Fig. 49) to the Hettangian–Sinemurian age, based on their lithologic affinities to the Hettangian–Sinemurian deposits occurring near Kalisz (Fig. 1). However, this view is unfounded as the deposits of "Kalisz series" in Wieluń KW-1 borehole contain palynomorphs (both megaspores and miospores) pointing to the Pliensbachian age (Marcinkiewicz, Rogalska, in: Deczkowski, 1967; Marcinkiewicz, 1971) — see also Dadlez, 1964 b. The Hettangian--Sinemurian deposits are generally absent from the Wieluń–

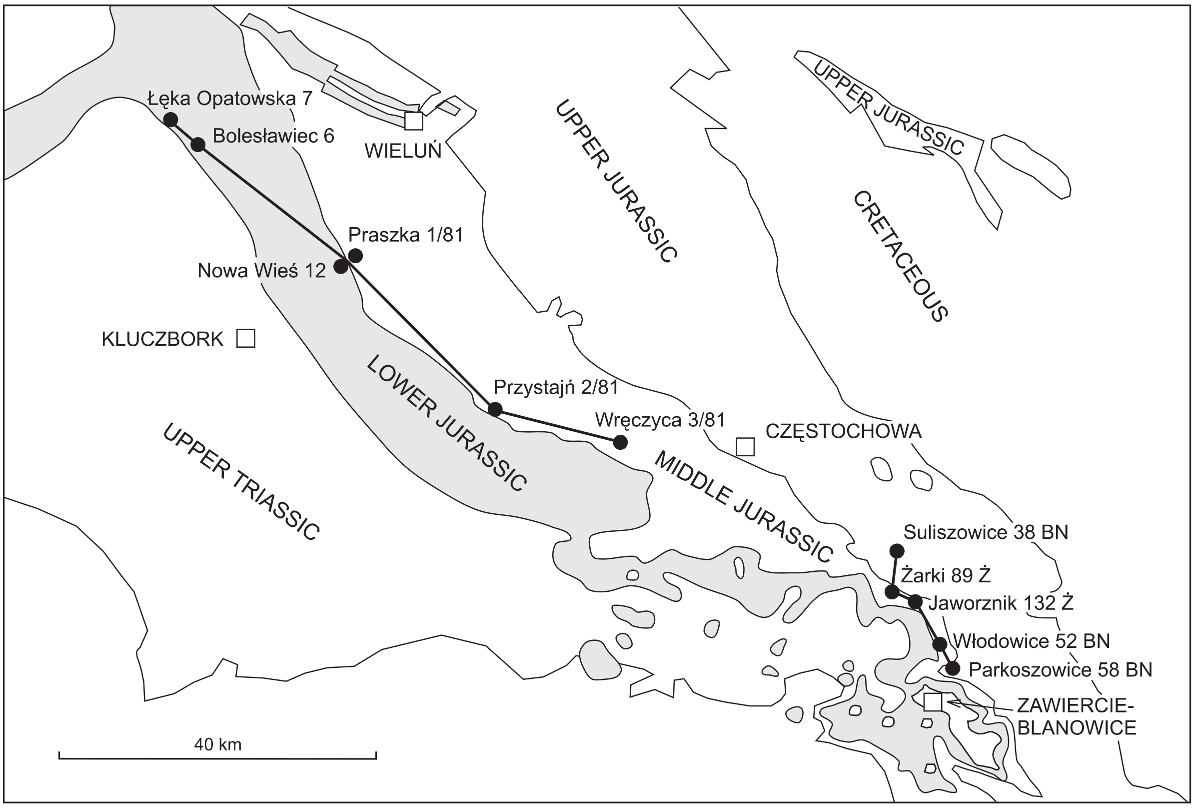

Fig. 49. Location of the boreholes and cross sections in the Częstochowa region

Częstochowa region. The Upper Triassic deposits, underlying the amalgamated sequence boundary below the Pliensbachian deposits, show intense kaolinization caused by a long non-depositional period, weathering and percolation of meteoric water, which is of crucial importance for clay minerals prospecting (Pieńkowski, 1988).

Deposits associated with this sequence are thin (maximum 17 m in the Przystajń borehole, Fig. 53 CD). In the NW part of the area studied (Łęka Opatowska borehole — Fig. 50 CD and Bolesławiec borehole — Fig 51 CD) the depositional sequence IV is developed as a fining-upward succession of grey sandstones, in places with trough-cross bedding. In Łęka Opatowska (Fig. 50 CD, depth 40–46 m), the sandstone lithofacies (the core is poorly preserved) is topped by dark-grey mudstone with plant roots and plant remains (palaeosol). In Bolesławiec (Fig. 51 CD) mudstone intercalations are more frequent and the whole sequence is only 2 m thick. The lithofacies and presence of fining-upward cycles point to alluvial (meandering river) depositional system. Nowa Wieś 12 borehole (Fig. 52 CD) terminated at the top of sequence IV, but nearby Praszka 1/81 borehole yielded the fully cored profile of the sequence IV (Pieńkowski, 1988, 1997). In Praszka borehole (Fig. 55), deposition starts with alluvial — meandering river depositional sequence represented by trough cross bedded sandstones. The next parasequence is developed as lagoonal deposits with trace fossils (fodinichnia) and plant detritus. The lower surface of these deposits is identified with the transgressive surface of depositional sequence IV. The lagoon was quickly filled in by the overlying deltaic deposits, which terminate the depositional sequence IV. In the south-easterly direction, the lagoonal deposits are gradually replaced by deltaic deposits (Przystajń 2/81 borehole, Fig. 53 CD), and further to SE by alluvial, meandering river deposits (Wręczyca 3/81 borehole, Fig. 54 CD). The lack of lagoonal deposits in both Łęka Opatowska 7–Bolesławiec 6 area and Wręczyca 3/81 area points to existence of an embayment or lagoon in the Praszka–Przystajń area. Maximum flooding surface of the depositional sequence IV is associated with the horizon with numerous trace fossils (fodinichnia) within the lagoonal-embayment deposits. Its non-marine correlative surface is probably associated with floodplain deposits in both Łęka Opatowska–Bolesławiec area and Wręczyca area.

Further to the SE (Suliszowice–Parkoszowice area, Fig. 61), the deltaic deposits of depositional sequence IV (mostly delta front — prodelta depositional subsystems) are thicker in the Suliszowice 38 BN borehole, where this sequence can be tentatively subdivided into three parasequences IVa–c (Fig. 56 CD — except for the lowermost, 0.5 m thick bed of coarse, possibly alluvial or strand line deposits). Six kilometres to the south (Żarki 89 Ż, Fig. 57 CD), a delta lobe with distributary facies had been built around an active river mouth. Increased influx of sediment delayed development of transgressive surface, although its non-marine correlative surface occurs at the base of sequence IV (Fig. 61; compare with Fig. 26). Deltaic deposits thin out to the SE, and locally (Włodowice 52 BN, Fig. 59 CD; Fig. 61) they are absent. In Włodowice 52 BN borehole transgressive deposits overlie directly the sequence boundary. Ravinement/reworking processes occurring during

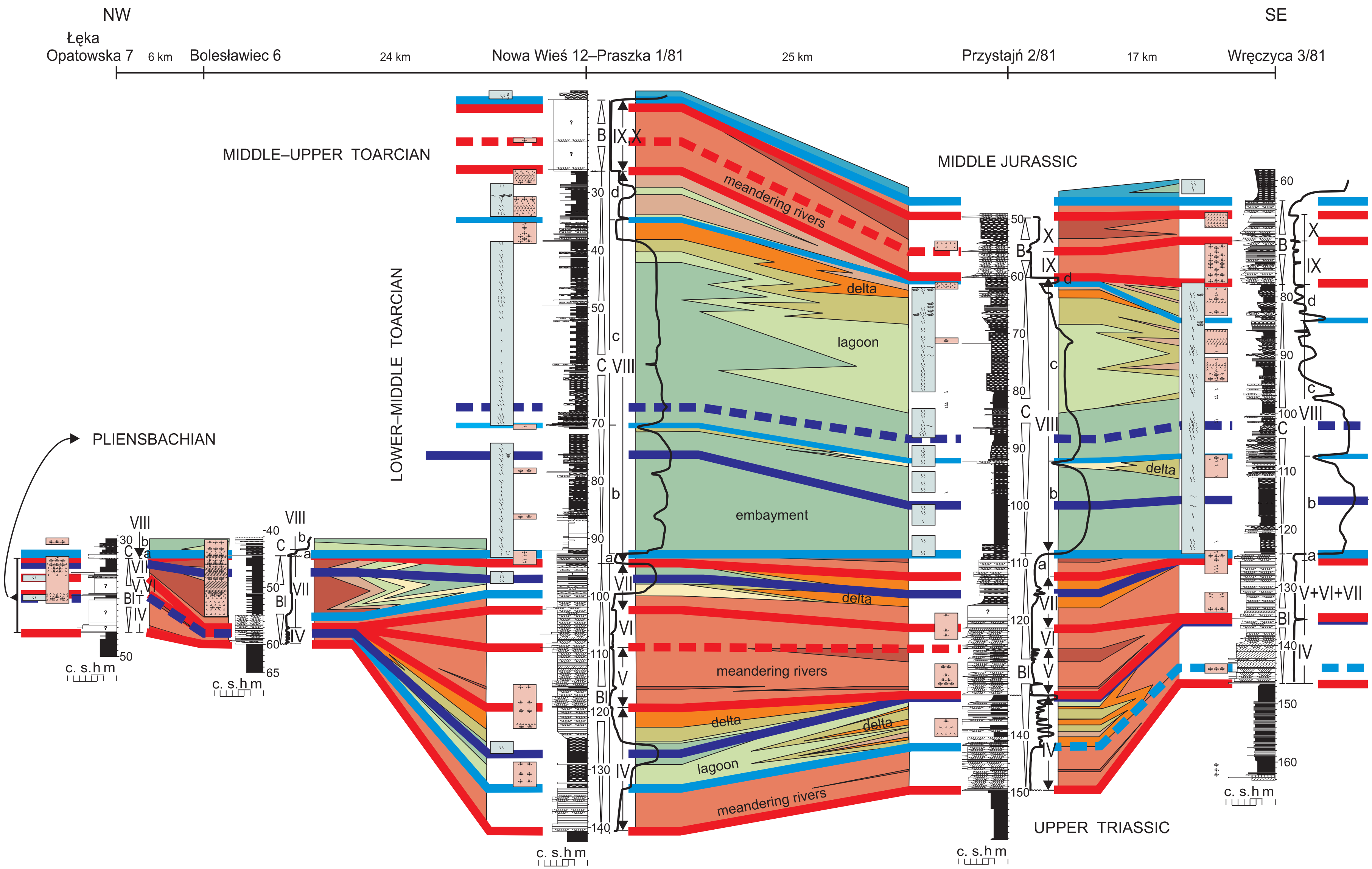

Fig. 55. Cross-section between Łęka Opatowska 7 and Wręczyca 3/81 showing development of depositional systems, depositional sequences and correlative surfaces

Reference horizon — transgressive surface of the depositional sequence VIII. Dashed navy-blue line marks a maximum flooding surface of the parasequence VIII c (dated to the late *falciferum* Zone), which passes laterally into the maximum flooding surface of the whole sequence VIII (see Fig. 61). In southern Poland, the maximum flooding surfaces of VIII b parasequence (*tenuicostatum* Zone) and VIII c parasequence (late *falciferum* Zone) are of similar magnitude, which is concordant with the data from the German Basin (Röhl *et al.*, 2001). Note amalgamated depositional sequences in the Pliensbachian deposits in the Łęka Opatowska 7–Bolesławiec 6 area and Wręczyca 3/81 borehole. For explanation see Fig. 16

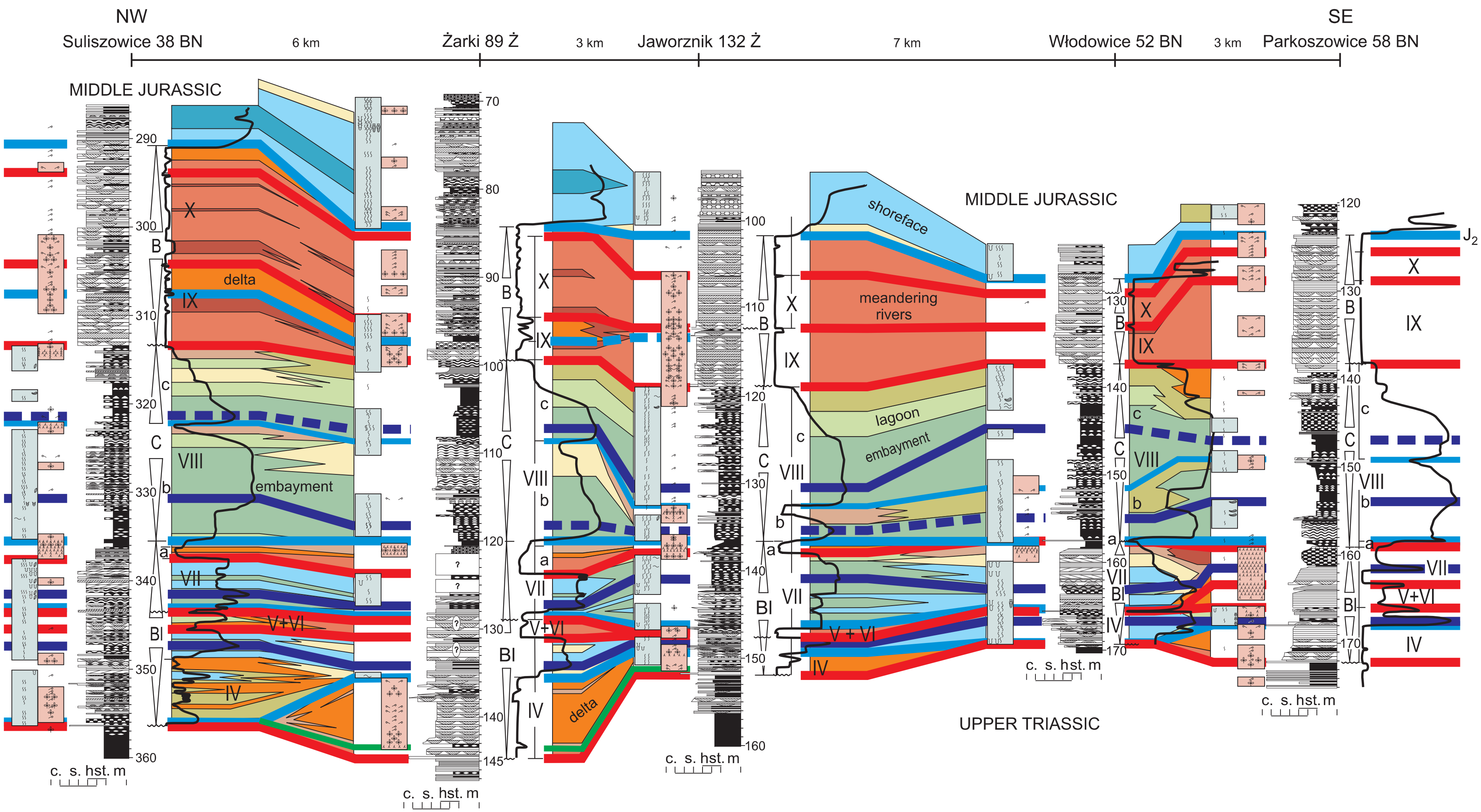

Fig. 61. Cross section between Suliszowice 38 BN and Parkoszowice 58 BN showing development of depositional systems, depositional sequences and correlative surfaces

Reference horizon — transgressive surface of the depositional seqeunce VIII. Note that the maximum flooding surface between Jaworznik 132 Ż and Włodowice 52 BN occurs in VIII b parasequence (*tenuicostatum* Zone), while between Suliszowice 38 BN and Parkoszowice 58 BN the maximum flooding surface is defined within the VIII c parasequence (late *falciferum* Zone). For explanation see Fig. 16

transgression completely reworked or removed underlying alluvial deposits. The next complex (parasequence IVc, Fig. 56 CD) is developed in an embayment-nearshore depositional system. Maximum flooding surface is situated within this complex. In Włodowice 52 BN borehole (depth 156.0–159.0 m) this complex is represented by high-energy, shoreface-foreshore deposits. Embayment- nearshore depositional system extends far to the SE (Parkoszowice 58 BN, depth 165.0–168.0 m, Fig. 60 CD). Marine bivalve *Cardinia phillea* d'Orbigny was found in this complex (Pl. I, 6).

Depositional sequence IV falls within the *Horstisporites planatus* megaspore zone (Late Sinemurian–Pliensbachian age, Fig. 2; Marcinkiewicz, 1971). Presence of *Cardinia phillea* d'Orbigny indicates Pliensbachian age of the sequence (Kopik, 1998).

DEPOSITIONAL SEQUENCES V AND VI

These sequences are very thin and they are absent from some places (Włodowice 52 BN, Fig. 59 CD). Usually, it is very difficult to distinguish sequences V and VI from each other. For example, in Wręczyca 3/81 borehole (Fig. 54 CD) all three sequences (V, VI and VII) represent amalgamated alluvial — meandering river deposits. Between Łęka Opatowska and Wręczyca (Fig. 55) both sequences are represented by the alluvial — meandering river deposits. Between Suliszowice and Parkoszowice, the depositional systems are more varied: deltaic-lagoonal facies occur in Suliszowice 38 BN borehole (depth 343.5–345.5 m, Fig. 56 CD), alluvial facies occur in Żarki 89 Ż borehole (Fig. 57 CD) and again deltaic facies occur in Jaworznik 132 Ż borehole (Fig. 58 CD) and Parkoszowice 58 BN borehole (Fig. 60 CD).

Depositional sequences V and VI fall within *Horstisporites planatus* megaspore zone (Late Sinemurian–Pliensbachian age, Fig. 2; Marcinkiewicz, 1971). Position above the occurrence of *Cardinia phillea* d'Orbigny points to a Pliensbachian age of the sequences (Kopik, 1998).

DEPOSITIONAL SEQUENCE VII

In the Łęka Opatowska–Bolesławiec area, this sequence is represented by coal-bearing deposits with numerous palaeosol horizons deposited by a lacustrine/backswamp depositional system. The thickness of coal deposits reaches some 6 m in the Bolesławiec 6 borehole (Figs. 51 CD, 55). Similar, but much thinner coal-bearing lacustrine facies occur in Włodowice 52 BN borehole (depth 157.5–158.5 m, Fig. 59 CD) and in Parkoszowice 58 BN borehole (Fig. 60 CD). The coal-bearing lacustrine depositional system is developed on the edges of the local embayments (Fig. 62: 2) and is associated with a penecontemporaneous embayment — lagoonal depositional system. This system was in turn coeval with the nearshore-embayment facies, well developed in the Nowa Wieś 12 borehole (depth 94.5–99.5 m, Fig. 52 CD) and further to SE in Suliszowice 38 BN borehole (depth 338.0–343.0 m), Żarki 89 Ż (depth 124.0–128.0 m), Jaworznik 132 Ż (138.0–147.0 m) and Włodowice 52 BN (depth 160.0–165.5 m). Noticeably, the range of nearshore-embayment facies of the sequence VII is approximately the same as in the sequence IV (Fig. 62), which is exceptional in the Polish Basin. It may point to a nearby connection with the Tethys. The coal-bearing lacustrine depositional system corresponds to the maximum flooding surface of depositional sequence VII, according to the rule suggested by Bohacs and Suter (1997) and Coe *et al*. (2003).

In the region near the town of Częstochowa (Wręczyca 3/81, Fig. 54 CD), amalgamated alluvial (meandering river) deposits representing sequences V, VI and VII indicates persistent alluvial sedimentation through Pliensbachian times ("Wręczyca River", Fig. 62: 1–3).

Deposits of sequences IV, V, VI and VII make up the Blanowice Formation (Fig 3). All four sequences are of Pliensbachian age, which is documented by megaspores (*Horstisporites planatus* megaspore zone — Marcinkiewicz, 1971) and position above the occurence *Cardinia phillea* d'Orbigny (Kopik, 1998).

DEPOSITIONAL SEQUENCE VIII

Over the whole area, the beginning of the sequence VIII is associated with an erosional surface and superimposed thin, alluvial deposits (parasequence VIIIa). In some places, the transgressive surface above the alluvial deposits is associated with ravinement and reworking of the underlying sediments (Nowa Wieś 12, depth 92.0 m; Wręczyca 3/81, depth 124.0 m; Włodowice 52 BN, depth 157.5 m — CD Figs. 52, 54, 59). In other places, the transgressing basin quickly drowned the underlying sediments. This process occurred in the areas of previous swamp (phytogenic) sedimentation (Bolesławiec 6, depth 43.0 m, Fig. 51 CD) and was probably accelerated by the high compaction rate of the underlying peat. Depositional sequence VIII is developed as embayment-lagoonal deposits (characteristic greenish-grey, in places also grey mudstones, claystones and heteroliths, Pl. XIII, 8). Occurrences of *Diplocraterion parallelum* Torell in some boreholes (Nowa Wieś 12, depth 75.0 m; Suliszowice 38 BN, depth 331.5 m — CD Figs. 52, 56), increased boron content (CD Figs. 53, 59, 60) and presence of dinoflagellate cysts (Barski, Leonowicz, 2002) point to brackish marine or marine conditions. On the other hand, presence of abundant plant detritus, phyllopods and palaeosols point to a relative shallowness of the basin and proximity of land. Open embayment deposits of a more pronounced marine character occur in some parts of parasequences VIIIb (Figs. 52 CD, 55, 56 CD, 61) and VIIIc (CD Figs. 56, 58, 59; Fig. 61). In the south-easterly direction, the thickness of parasequence VIIIb diminishes and the embayment deposits are replaced by deltaic deposits. Interestingly, maximum flooding surface of the depositional sequence VIII occurs within parasequence VIIIb between Łęka Opatowska 7 and Wręczyca 3/81 (Fig. 55), while between Suliszowice 38 BN and Parkoszowice 58 BN (Fig. 61) it occurs either in the parasequence VIIIb (Suliszowice, Żarki, Parkoszowice) or parasequence VIIIc (Jaworznik, Włodowice). The maximum sea level in both parasequences was in fact very similar and choosing which parasequence maximum flooding surface (that of parasequence VIIIb or VIIIc) should be defined as the maximum flooding

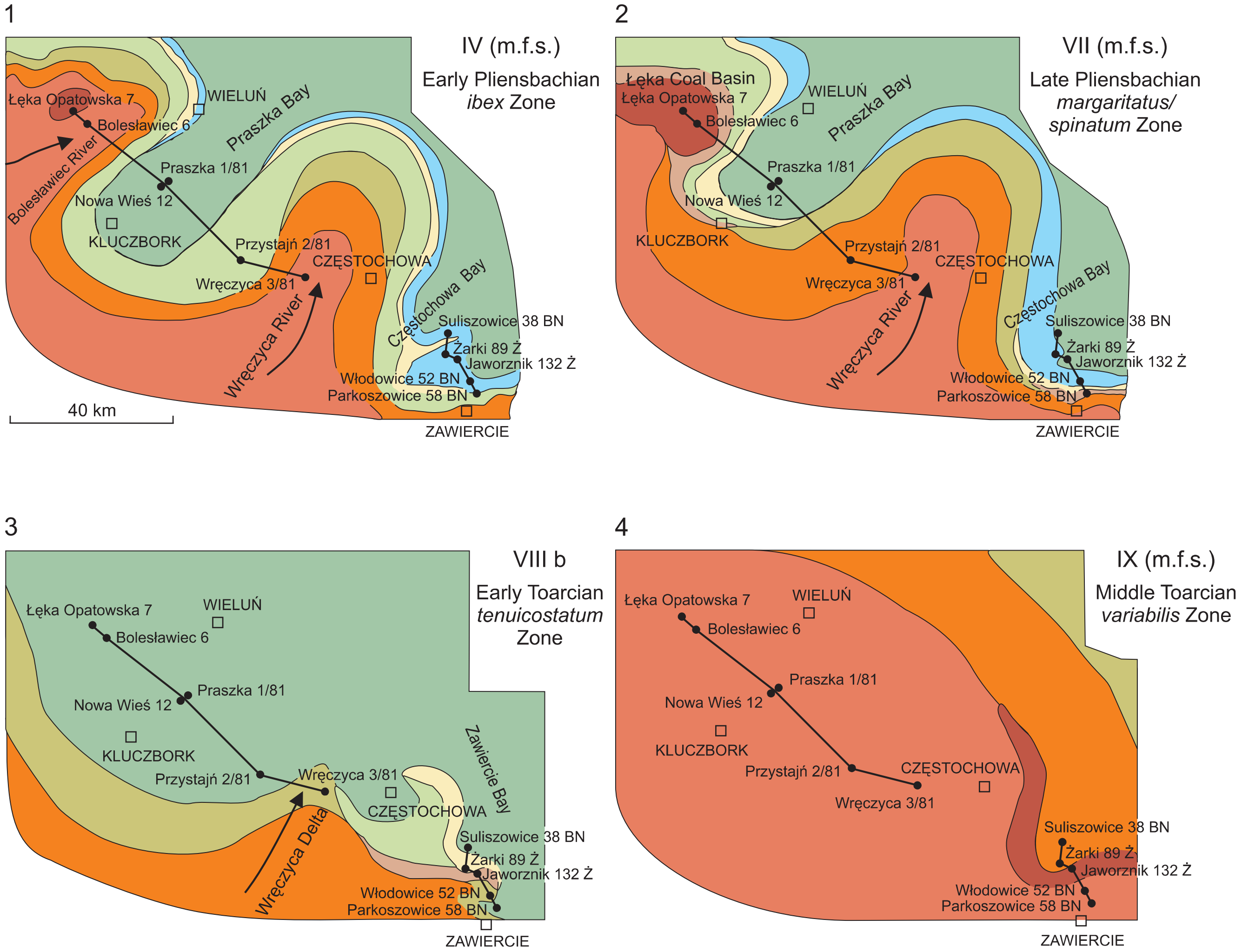

Fig. 62. Palaeogeographical maps of the Częstochowa region, showing spatial development of depositional systems in the Pliensbachian and Toarcian times

Note some persistent palaeogeographical features, like area around Wręczyca 3/81with increased river discharge and sediment supply (the Wręczyca river/delta) and the Częstochowa Bay. The Bolesławiec River and Praszka Bay were less persistent. A local coal basin developed in the western part of the Częstochowa region in the latest Pliensbachian times and very conspicuous expansion of the basin occurred in the Early Toarcian times. For explanation see Fig. 16

surface of the whole sequence VIII depends on local sedimentary conditions, chiefly sediment supply. Both maximum flooding surfaces (VIIIb and VIIIc) are separated by sediments characteristic of a shallowing stage, such as nearshore-deltaic--marshy deposits, with palaeosol horizons developed in more marginal parts of the basin. Plant roots and emersion/palaeosol surfaces occur in Wręczyca 3/81 borehole (Fig. 54 CD) and in Suliszowice 38 BN (Fig. 56 CD).

Estimation of sedimentary accommodation space obtained from the regularly prograding successions occurring between the maximum flooding and emersion surfaces in these two boreholes shows that the maximum depth of the basin was about 14 m (assuming compaction factor of 1.6).

As it was mentioned above, the next parasequence (VIIIc) is similar to parasequence VIIIb. The basin was generally of more shallow (lagoonal) character in the Praszka–Wręczyca area (Fig. 55). This is proved by a more abundant plant detritus; *D. parallelum*Torell burrows are absent from this area within this parasequence. However, the basin between Żarki and Parkoszowice was equally deep or deeper than this of the parasequence VIIIb (Fig. 61 — note also elevated boron content in Włodowice 52 BN, depth 144.0–145.0 m, Fig. 59 CD, or distal storm deposits (tempestites) in Parkoszowice 58 BN, depth 145.0–150.0 m, Fig. 60 CD). The parasequence VIIIc ends with prograding deltaic deposits. The parasequence maximum flooding surface, running within embayment deposits in the lower part of parasequence VIII c, is easily recognisable in superregional scale and is of important correlative significance in the whole Polish Basin. This surface probably coresponds to the maximum flooding event in Toarcian of Europe.

Depositional sequence VIII is of the constant character over the whole Częstochowa region and in the whole basin in Poland. It is assigned to the Early Toarcian age. Finds of dinoflagellate cysts *Luehndea spinosa* (Morgenroth) in Ciechocinek Formation in Kozłowice and Boroszów exposures, Częstochowa region (Barski, Leonowicz, 2002) allowed more precise dating of the lower part of this sequence. This palynomorph spans, inclusively, the *margaritatus* Zone (Late Pliensbachian) and *tenuicostatum* Zone (Early Toarcian) age. Moreover, occurrence of megaspores *Paxillitriletes phyllicus* (Murray) Hall et Nicolson and *Minerisporites institus* Marcin- kiewicz and lack of *Horstisporites planatus* (Marcinkiewicz) Marcinkiewicz (Fig. 2; Marcinkiewicz, 1971) provide a strong argument that the transgressive deposits of sequence VIII are of the Early Toarcian age (Koppelhus, Nielsen, 1994).

DEPOSITIONAL SEQUENCES IX AND X

These sequences are developed mostly as alluvial, meandering river deposits with subordinate lacustrine lithofacies. Deltaic deposits occur between Suliszowice 38 BN (Fig. 56 CD) and Żarki 89 Ż boreholes (Fig. 57 CD). Development of the delta depositional system was preceded by a short-lived brackish-marine ingression associated with lagoonal mudstones and heteroliths. These mudstones and heteroliths show somewhat higher boron content, presence of pyrite concretions and more abundant fodinichnia. This "deltaic episode" was associated with depositional sequence IX (Fig. 61). Depositional sequence X is developed as alluvial deposits (sandstones with trough cross bedding and rich plant fossils) with some intercalations of lacustrine deposits. Sequence boundaries are tentatively placed at the bottoms of coarse-grained, usually conglomeratic deposits. The uppermost sequence boundary commences depositional sequence XI, which is associated with Middle Jurassic deposits, although the basal alluvial deposits overlying the sequence boundary may be of the latest Toarcian age.

* * *

An Early Jurassic sedimentary succession and palaeogeography in the Częstochowa region is presented in Fig. 62. The maps were constructed based on analysis of coeval depositional systems at chosen "time horizons" inferred from correlative bounding surfaces. Several long-lasting palaeogeographical elements are visible: the Praszka Bay, the Częstochowa Bay and the Łęka Coal Basin in Pliensbachian times and Wręczyca River (or delta), which was active during most of the Pliensbachian/Toarcian times. The Częstochowa region yielded information on the facies architecture of marginal parts of the Early Jurassic basin in Poland, showing generally highly reduced thickness, numerous hiatuses representing relatively long time intervals and "amalgamated" sequence successions.

Deposits of sequences IV, V, VI and VII are assigned to the Blanowice Formation (= "sub-coal beds"), sequence VIII is identified with the Ciechocinek Formation, and sequences IX and X, with lowermost part of sequence XI, represent the Borucice Formation (Fig. 3).

EARLY JURASSIC SEDIMENTATION IN THE WIELKOPOLSKA REGION

Sedimentation in the Wielkopolska region is characterised based on the fully cored Pobiedziska IGH-1 borehole (Fig. 63 CD), situated East of the town of Poznań (Fig. 1). This core comprises Hettangian, Sinemurian and Plliensbachian deposits. The Toarcian section was not cored.

This setting is associated with a reduced thickness of Early Jurassic sediments on the slope of Wielkopolska Ridge (Dadlez, Franczyk, 1976). The reduced thickness of Lower Jurassic deposits (which are totally ~300 m thick) affected particularly Hettangian and Sinemurian deposits and was associated with local tectonic movements, accelerated by rock salt translocations in the basement. Lower Toarcian deposits (Ciechocinek Formation) show only slight thickness reduction, but the Upper Toarcian deposits are absent.

DEPOSITIONAL SEQUENCE I

Sediments of depositional sequence I rest on an erosional surface (sequence boundary). Underlying sediments are represented by red-beds of the Norian age (Gajewska, 1997); Rhaetian deposits are missing. This depositional sequence is generally developed in alluvial facies (meandering or braided river deposits) represented by medium- to coarse-grained sandstones with subordinate conglomerates. There are three remarkable mudstone intercalations (Pobiedziska IGH-1,depth 1577.0–1578.5; 1566.0–1567.0; 1554.0–1555.0 m). The mudstone intercalations (prticularly those between 1566.0–1567.0 m and 1554.0–1555.0 m) represent sharp lithofacies changes and were probably associated with rapid base level rises. The second interval shows conspicuously higher boron content, which points to a short-lived incursion of saline water (lagoonal-coastal plain depositional system), possibly associated with the maximum flooding. The maximum flooding surface allows a tentative subdivision of the whole sequence into the TST (parasequences b–f) and HST (parasequences f–k) systems tracts. Thus, deposits with high boron content (1586.0–1587.0 m) would represent the maximum flooding surface of parasequence If, probably reflecting maximum expansion of the basin in the *liasicus* Zone.

DEPOSITIONAL SEQUENCE II

This sequence rests on an erosional surface and commences with 3 m of pebbly, coarse-grained sandstone with trough cross bedding. This bed was deposited by a meandering or braided river system, dominated by bed-load processes. The sandy-conglomeratic bed is followed by grey sandstones and a mudstone bed with abundant plant fossils. This mudstone bed (Fig. 63 CD, depth 1546.5 m) contains some pyrite concretions and may represent a continental correlative surface of transgressive surface. Overlying coarse, cross bedded sandstones are monotonous (depth 1517.0–1541.0 m) and they may represent parasequence IIb. The maximum flooding surface of depositional sequence II is probably missing, possibly due to a subsequent erosion of the uppermost parasequence IIc. An erosional surface at the depth 1517.0 m with quartz pebbles is regarded as the next sequence boundary.

DEPOSITIONAL SEQUENCE III

As the bulk of previous sequences, this sequence commences with a sandstone lithofacies with trough cross bedding (Fig. 63 CD, depth 1489.0–1508.0 m — parasequence IIIa). Seven fining-upward cycles have been distinguished within this interval. They show gradual upward decrease of both average grain size and thickness of individual cycles. The transgressive surface occurs at the depth 1489.0 m. It is overlain by lithofacies showing features of transgressive facies, such as much better sorting, presence of varied trace fossils, hummocky cross stratification and much higher boron content in mudstones. These transgressive sediments of parasequence IIIb are developed by a nearshore depositional system and they are represented by white-grey, fine-grained sandstones with hummocky cross stratification (lower shoreface depositional subsystem). They are followed by slightly coarser, laminated sandstones with *Skolithos*. The sandstones with *Skolithos* represent an upper shoreface-foreshore depositional subsystem, which terminates the parasequence IIIb. The next parasequence IIIc starts with flooding surface covered by offshore heteroliths. The maximum flooding surface of depositional sequence III is placed within these heteroliths. The overlying, 8 m thick nearshore (shoreface) sandstones are topped with laminated and cross-bedded sandstones with dispersed pebbles and abundant plant fossils and mudstone beds. These strata (1463.5–1472.0 m) are characterised by an upward decrease of boron content and they represent a coarsening-upward succession of a prograding delta. At the depth 1463.5 m this succession is interrupted by an erosional surface covered by coarse-grained, conglomeratic sandstones with quartz pebbles and mud clasts. This surface marks the sequence boundary of depositional sequence IV.

DEPOSITIONAL SEQUENCE IV

This sequence commences with the two metres thick coarse-grained, conglomeratic sandstone. Higher up in the section, the grain size and thickness of minor fining-upward cycles diminish. Also thickness of ten superimposed fining-upward cycles diminishes upwards. The interval between 1444.5 m and 1462.0 m represents medium- to coarse-grained, trough cross bedded sandstones deposited by an alluvial, meandering or braided river depositional system. Drifted plant remains are very abundant. This interval is identified with the parasequence IVa.

A ravinement surface (transgressive surface) occurs at 1444.5 m. It is overlain by conglomeratic lag, representing residual deposits left over after marine reworking of underlying fluvial sediments (typical strand-line deposits). The strand-line deposits are overlain by fine-grained sandstones. These sandstones contain calcareous cement and are horizontally laminated in the lower part they, while in the higher part they show hummocky cross stratification (Fig. 63 CD, depth 1440.5– 1444.5 m). These strata represent foreshore sediments passing into the shoreface deposits. The overlying 50 cm thick flaser heteroliths represent the lower shoreface depositional subsystem with the parasequence IVb maximum flooding surface. The overlying strata of parasequence IVb represent progradational, regressive succession.

Parasequence IVb contains possibly the tidal deposits, which are rare in the Early Jurassic deposits of Poland. Features pointing to the tide-influenced shore zone depositional system have been discussed in detail in the chapter describing depositional systems. The 5 m-thick succession between 1435.0–1440.0 m (Fig. 63 CD) shows characteristic bi-directional "rhytmites" with mud drapes and frequent, regularly repeating erosional surfaces with mud clasts. *Diplocraterion paralellum* Torell dwelling structures, bivalve resting tracks of *Lockeia amygdaloides* (Seilacher)and fodinichnia are common. It points that the mesotidal facies could develop in central Poland at least in the Early Pliensbachian times.

The tidal deposits are covered by coarsening-upward, progradational succession of nearshore (shoreface-foreshore), high-energy sandy deposits showing various cross bedding sets. This section, topped with medium- to coarse-grained foreshore sandstones, represents a wave- dominated (possibly still tide-influenced) shoreface-foreshore depositional system.

The whole nearshore-tidal succession between 1428.0 and 1444.5 m builds up the parasequence IVb, represented by prograding nearshore/tidal facies.

The next parasequence IVc starts with conspicuous flooding surface marked by calcareous heteroliths, quickly passing into medium-grained, laminated sandstones representing a high-energy shoreface depositional subsystem with abundant and diversified trace fossils (including *Diplocraterion parallelum* Torell, pointing to the marine salinity). Storm events are represented by the scouring surfaces with mud clasts and escape structures (fugichnia). A brief shallowing trend, probably caused by higher sediment input, is followed by deeper facies (heteroliths) of an offshore depositional system with the maximum flooding surface of the depositional sequence IV (Fig. 63 CD, depth 1417.2 m). Overlying sediments represent a shoreface depositional subsystem (depth 1414.0–1418.0 m) characterised by a higher boron content. The shoreface deposits are followed by quick progradation of deltaic sediments (depth 1412.0–1413.5 m), which end the sequence IV. The erosional surface (depth 1412.2 m) represents beginning of the next depositional sequence V.

DEPOSITIONAL SEQUENCE V

The sequence begins with erosional surface (Fig. 63 CD, depth 1412.2 m) covered by a conglomeratic lag composed of mud clasts. Overlying trough cross bedded, medium grained sandstones represent an alluvial depositional system (meandering river or distributary channels — parasequence Va). The transgressive surface occurs at the depth of 1410.5 m and begins deposition of shoreface deposits represented by fine-grained sandstones with hummocky cross stratification, containing trace fossils (domichnia) and tempestites. The maximum flooding surface is placed at the mudstone intercalation (Fig. 63 CD, depth 1408.0 m). A whole succession represented by the nearshore sediments (shoreface depositional subsystem) builds up the parasequence Vb. This is the last parasequence of the depositional sequence V, but the lack of younger parasequences is probably caused by subsequent erosion.

DEPOSITIONAL SEQUENCE VI

The erosional surface at the base of depositional sequence VI is very conspicuous (Fig. 63 CD, depth 1398.5 m). Moreover, the erosional hiatus must have been substantial as the coarse-grained alluvial deposits lie directly on the shoreface, basinal deposits. It is possible that the lacking parasequences Vc, Vd and Ve, known from the Holy Cross Mts region (Fig. 46 CD) and from Pomerania region (Fig. 31 CD), have been eroded away. The sediments of depositional sequence VI are thin (less than 10 m) and composed entirely of coarse-grained, alluvial deposits (meandering or braided river depositional system). Small thickness of the sequence VI may be also connected with a subsequent erosion, preceding deposition of the depositional sequence VII.

DEPOSITIONAL SEQUENCE VII AND HIGHER SEQUENCES

The erosional surface (sequence boundary) at the depth 1383.8 m (Fig. 63 CD) is covered by conglomeratic sandstones containing numerous quartz pebbles and mud clasts pointing to erosion of underlying sediments. Similarly to the depositional sequence VI, the lower part of depositional sequence VII (parasequences VIIa) is composed of coarse-grained, trough bedded sandstones with numerous drifted plant fossils. These facies represent meandering or braided river depositional system. Overlying sediments (depth 1358.0–1370.0 m) are represented by medium- and fine-grained sandstones with trough cross bedding deposited in an alluvial, meandering river depositional system. Uppermost part of this package with very abundant plant fossils may represent distributary channels.

The transgressive surface of sequence VII occurs at the depth 1358.0 m. The overlying sediments are represented by white-grey, laminated sandstones representing nearshore (foreshore–shoreface) depositional system, beginning the next parasequence VIIb.

The section above 1354.0 m was not cored (except for several short, about 1 m-long intervals). The approximate lithological profile of the rest of sequence VII and depositional sequence VIII is interpreted based on neutron-gamma wire-logs. Sequences IX and X are probably absent from Pobiedziska IGH-1 borehole or they are very thin (Feldman-Olszewska, 1998).

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Besides general reduction in the thickness of Hettangian–Pliensbachian deposits (their thickness slightly exceeds 350 m), the Pobiedziska profile shows generally a more continental character than the other profiles from the Mid-Polish Trough. Most of the sequences are built of coarse-grained alluvial facies, deposited probably by altered braided and meandering depositional systems. Marginal-marine depositional systems are reported from the Upper Sinemurian, Lower Pliensbachian, Upper Pliensbachian and Lower Toarcian deposits, although the latter are known only fragmentary. The positions of correlative surfaces representing the Hettangian and Lower Sinemurian transgressive surfaces and maximum flooding surfaces are interpreted based on occurrence of mudstones, which are sometimes rich in boron. Thus, the mudstone intercalations may reflect weak influences of saline waters, associated with a lagoonal (“bay-line”) depositional system. These strata probably correspond to the correlative non-marine surfaces of flooding events. All the erosional surfaces representing sequence boundaries are very conspicuous and they are associated with coarse, conglomeratic facies of alluvial origin. Significant hiatuses were probably connected with the lower boundary of sequence I, the sequence I/II boundary and the sequence V/VI boundary, as shown by lithofacies contrasts and inferred erosion scale. Specific lithofacies development implies a different lithostratigraphic division, with significantly expanded Zagaje Formation and lack of the Skłoby Formation and Przysucha Ore-bearing Formation (see the chapter on lithostratigraphy and Fig. 3). Stratigraphy of the Early Jurassic deposits in Pobiedziska IGH-1 borehole is based on megaspore finds (Marcinkiewicz, pers.comm.) and sequence stratigraphy.

EARLY JURASSIC SEDIMENTATION IN THE FORE-SUDETIC MONOCLINE

Characterization of Early Jurassic depositional systems and sequences in the Fore-Sudetic Monocline (Fig. 1) is based on one fully cored borehole — Gorzów Wielkopolski IG 1 (Fig. 64 CD). The borehole was drilled in the late fifties and some intervals of the core are poorly preserved and some fragments are lacking. Therefore the profile was confronted with neutron-gamma wire-log and with previous lithological and paleontological description performed in the early sixties (Dadlez, Marcinkiewicz, 1964). Comprehensive biostratigraphical subdivision of the Gorzów Wielkopolski IG 1 borehole section, based on megaspores, was published by Marcinkiewicz (1971, her table 5). Recent studies on dinoflagellate cysts are in progress (Gedl, in prep.). Gorzów Wielkopolski IG 1 is located outside the Mid-Polish Trough, which results in diminished subsidence and, consequently, with reduced thickness of the Lower Jurassic sediments (~ 376 m).

DEPOSITIONAL SEQUENCE I

The Lower Jurassic sediments rest on the grey mudstones of Wielichowo beds, probably of the an Early Rhaetian age (Gajewska, 1997). The lowermost Jurassic sediments are represented by grey sandstones and mudstones and their age is established as the Hettangian–Lower Sinemurian, based on finds of *Nathorstisporites hopliticus* Jung megaspore (Marcinkiewicz, 1971). These lowermost sediments of depositional sequence I are disturbed by a local fault zone, which was encountered at the depth 1130.0–1137.0 m. Between 1125.2 and 1132.0 m, the grey, medium-grained sandstones with trough cross bedding prevail. This succession is interpreted as a parasequence represented by facies deposited by an alluvial (most probably meandering river) depositional system. The grey mudstones with plant remains and siderite nodules occurring between 1122.0 and 1125.2 m represent a lacustrine depositional system. These mudstones probably correspond to the parasequence Ib. The boundary between alluvial and lacustrine sediments (1125.2 m) probably represents the continental correlative of transgressive surface of the depositional sequence I. The overlying grey, medium-grained sandstones with trough cross bedding (1118.5–1122.0 m) represent recurring alluvial sedimentation (progradation stage). Uppermost part of this section can represent a delta plain facies, as shown by palynofacies record.

The transgressive surface occurs at the depth of 1118.5 m. This transgressive surface marks the base of a set of parasequences Ic–e (the individual parasequences are probably amalgamated within sandstones between 1112.0 and 1118.5 m). These sandstones show tabular cross bedding, horizontal lamination and hummocky cross stratification and they contain brackish-marine bivalves and abundant calcareous cement both in the lowermost, 2 m thick interval and in the uppermost section. These sandstones represent mostly a shoreface depositional subsystem. Mudstones and calcareous sandstone-mudstone intercalations with hummocky cross stratification occurring between 1107.5 and 1112.0 m point to a deeper, shoreface–offshore transition zone. Dinoflagellate cyst *Liasidium variabile* Drugg has been found at the depth 1112.0 m (Gedl, pers. comm.). According to Brenner (1986), this palynomorph occurs in the Late Hettangian of southwest Germany. Riding and Thomas (1992) confirmed, that its first stratigraphical appearance datum in continental Europe is earlier than in England (Late Sinemurian), casting doubts on the Sinemurian age of its appearance. On the other hand, Poulsen and Riding (2003) maintained their view of Sinemurian age of this palynomorph. The appearance of *Liasidium variabile* Drugg in Gorzów Wielkopolski IG 1 is probably even earlier than in Germany (the upper limit of *Pinuspollenites–Trachysporites* pollen assemblage in this borehole is located some 12 m above the occurence of *Liasidium variabile* Drugg). Consequently, the age of this palynomorph is probably of a broader range than believed before. The maximum flooding surface of depositional sequence I, dated at a mid-Hettangian age, occurs at a depth of 1111.0 m and broadly coincides with the *Liasidium variabile* Drugg occurrence. It is thought to be associated with the parasequence If. Accordingly, the whole succession between 1111.0 and 1132.0 m would represent the transgressive systems tract of depositional sequence I. Above the maximum flooding surface, the palynofacies show gradual shallowing and isolation of the basin resulting in development of a barrier-lagoon depositional system, topped with mudstone containing palaeosol level with plant roots and coal (marsh depositional subsystem). The overlying sediments represent mixed barrier-lagoon–marshy-delta plain deposits with three flooding surfaces associated with embayment lithofacies and they contain more abundant ichnofauna, brackish-marine bivalves, agglutinated foraminifera and Acritarcha. These strata (1096.5–1111.0 m) would represent parasequence set Ig–k ? (the highstand systems tract of depositional sequence I). A sample from the depth of 1102.6 m yielded numerous miospores, including *Pinuspollenites minimus* (Couper) Kemp, *Concavisporites toralis* (Leschik) Nilsson, *C. divisitorus* Kedves & Simoncsics, *Dictyophyllidites mortoni* (de Jersey) Playford & Dettman. Collectively, these taxa point to the Hettangian age (*Pinuspollenites–Trachysporites* zone).

The section represented by continental deposits (1118.5–1132.0 m) have been assigned to the Zagaje Formation, and the strata representing nearshore-barrier/lagoon-deltaic deposits (1096.5–1118.5 m) belong to the Skłoby Formation. Both lithoformations are reduced in their thickness. The age of the sequence I falls within the *Nathorstisporites hopliticus* megaspore zone (Hettangian–Early Sinemurian). Characteristic miospores of the *Pinuspollenites–Trachysporites* zone occurring in this sequence allow narrowing its age to the Hettangian.

DEPOSITIONAL SEQUENCE II

An erosional surface (1095.5 m) is interpreted as the sequence boundary. Erosion was probably significant and it removed part of the underlying sediments of depositional sequence I. The sequence boundary is covered with conglomeratic lag and coarse-grained or medium-grained, poorly sorted sandstones. This section is interpreted as the alluvial facies passing upwards into deltaic facies (parasequence IIa). The erosional sequence boundary marks also the base of Ostrowiec Formation.

The core interval between 1050.0 and 1095.5 m is poorly preserved and sedimentological interpretation is largely based on palynofacies characteristics obtained from several mudstone intercalations. Palynofacies point generally to the lagoonal/

embayment depositional system. Sandstones may represent either the barrier-nearshore facies or deltaic-distributary facies. Better core recovery from the interval between 1028.5 and 1056.0 m allowed interpretation of these strata (wavy and lenticular heteroliths with intercalations of calcareous sandstones representing tempestites) as the facies of a nearshore depositional system, mostly offshore–shoreface transition zone. Ichnofauna is fairly rich, representing mainly deposit feeders (fodinichnia) and some domichnia (suspension feeders). Palynofacies are typical of an offshore–shoreface environment, dinoflagellate cysts (Gedl, pers. comm.) and Acritarcha point to a marine–brackish-marine conditions. The maximum flooding surface is placed on depth 1043.5 m, within the mudstone intercalation showing an open-basin, offshore palynofacies.

The nearshore depositional system is replaced by the barrier-lagoon depositional system (depth 1028.5–1033.0 m), represented by grey-brownish mudstones with siderite bands and plant detritus. These deposits terminate deposition of the depositional sequence II.

The age of the depositional sequence II falls within the *Nathorstisporites hopliticus* megaspore zone (Hettangian–Early Sinemurian). The guiding miospore *Aratrisporites minimus* Shultz indicates the same age. The uppermost occurrence of this miospore has been reported at the depth of 1034.0 m (Rogalska, 1976). The sequence II is assigned to the lower Ostrowiec Formation.

DEPOSITIONAL SEQUENCE III

An erosional surface at the depth of 1028.5 m is identified with the sequence boundary. The sequence boundary is covered by the medium-grained, poorly sorted sandstones. A poorly preserved core does not allow recognition of sedimentary structures, but a sharp lithological contrast with the underlying lagoonal mudstones suggests a fluvial origin of the interval between 1025.0 and 1028.5 m (parasequence IIIa).

Mudstone intercalation occurring between 1023.0 and 1024.0 m shows the typical offshore palynofacies with dinoflagellate cysts and Acritarcha, which points that the transgressive surface occurs below this intercalation.

The core interval between 987.5 m and 1023.0 m is poorly preserved and interpretation of this section is based largely on palynofacies description. The palynofacies point generally to the offshore/embayment depositional system, separated by the nearshore/barrier facies represented by sandstones. A sample taken from the depth of 997.0 m shows the typical offshore palynofacies characterised by rare palynomacerals and sporomorphs (pollens are dominating) and presence of Acritarcha and dinoflagellate cysts. This bed is interpreted as the maximum flooding surface. The strata between 980.2 and 987.5 m are built of the heteroliths interpreted as lagoonal-embayment deposits. These strata end sedimentation of the depositional sequence III.

The whole sequence shows significant share of the facies deposited by a nearshore depositional system and due to the poorly preserved core it was only tentatively subdivided into three parasequences. Occurrence of *Horstisporites planatus* megaspore points to the Late Sinemurian–Pliensbachian age. Depositional sequence III is assigned to the Ostrowiec Formation.

DEPOSITIONAL SEQUENCE IV

The erosional surface with mud clasts, occurring at depth 980.2 m, is conspicuous and represents the sequence boundary. The overlying trough cross bedded sandstones and dark-grey mudstones are rich in plant fossils and they represent facies of delta plain and distributary channel depositional subsystems (this interpretation is also confirmed by palynofacies). The transgressive surface at depth 978.0 m is connected with heavily bioturbated sandstones. These sandstones commence the facies of a shoreface depositional system, developed between 969.0 and 978.0 m (parasequence IVb). Trace fossils, as well as marine bivalves, are numerous and diversified. Chamosite is frequent. Storm cycles are also characteristic (Pl. IX, 5). The transgressive surface marks the lower boundary of Gielniów Formation, characterised by domination of marine/nearshore facies. The parasequence IVb is of the type 2 (marine) parasequence (Fig. 26), characterised by the sediments associated with a rapid flooding, passing quickly into deposits associated with a parasequence maximum flooding surface (marine heteroliths). The maximum flooding sediments gradually pass upward into the high-energy, storm-dominated medium-grained sandstones deposited by a upper shoreface subsystem. The next parasequence (IVc) begins with flooding surface, which commences development of the offshore deposits (lenticular to wavy heteroliths). The distal tempestite beds are frequent (see Fig. 7). Marine conditions, probably of a somewhat stressed character, are confirmed by numerous (although not very diversified) foraminifera, bivalves, Acritarcha and dinoflagellate cysts. The palynofacies point to a marine, offshore depositional system, although the relatively high frequencies of palynomorphs and spores indicate a relative proximity of shoreline and storm-induced transport of palynomacerals. The maximum flooding surface of depositional sequence IV (depth 965.0 m) is marked by the finest fraction and the most “marine” palynofacies with dinoflagellate cysts (Gedl, pers. comm.). Upper part of the parasequence IVc (depth 945.2–960.0 m) is represented by a shallowing, prograding succession (the offshores–shoreface transition facies passing into the shoreface facies). The core representing an uppermost part of parasequence IVc is missing, but based on archival descriptions this interval is dominated by fine-grained, well-sorted sandstones. Similarly to the parasequence IVb, parasequence IVc is built up of the type 2 parasequences (Fig. 26).

DEPOSITIONAL SEQUENCE V

The lower boundary of depositional sequence V occurs within an interval with poorly preserved core, but presence of medium- to coarse-grained sandstones suggests occurrence of the sequence boundary with basal sediments belonging to the next depositional sequence. The overlying fragments of grey and pink sandstones with plant fossils and ferruginous concretions (depth 943.0–948.0 m, parasequence Va) are interpreted as facies of a delta front depositional subsystem.

Heteroliths between 941.0 and 942.0 m show basinal, offshore features (marine palynofacies and abundant trace fossils). It means, that the transgressive surface of the depositional sequence V should be placed below these heterolithic strata.

The whole core interval between 914.2 and 940.8 m is poorly preserved. Fragments of core with heteroliths contain palynofacies pointing to an offshore depositional system. The fine-grained sandstones prevailing in this interval represent probably a nearshore (shoreface) depositional system. The maximum flooding surface is placed at the depth 934.0–935.0 m, where palynofacies point to an offshore environment (very few palynomacerals). It allows subdivision of the depositional sequence V into the TST and HST systems tracts. The uppermost part of depositional sequence V contains more intercalation of the medium-grained sandstones, which point to a shallowing of the sedimentary basin. Two to four parasequences can be distinguished, but only tentatively due to a poorly preserved core.

Depositional sequence V falls within *Horstisporites planatus* megaspore zone (Marcinkiewicz, 1971), which points to the Late Sinemurian–Pliensbachian age. The depositional sequences IV and V show mostly a marine/nearshore character and they build up the Gielniów Formation (Fig. 3).

DEPOSITIONAL SEQUENCE VI

Depositional sequence VI is relatively thin. Sedimentation of this sequence was preceded by significant erosion. The erosional surface occurring at the depth 914.2 m is very conspicuous. The erosional surface is covered by a conglomeratic lag composed of large mud clasts deriven from eroded underlying mudstones. This surface is correlated with the lower boundary of depositional sequence VI. Similarly to the other regions in Poland, this erosion is probably associated with significant non-depositional/erosional hiatus. The beginning of sedimentation followed a rise of base level, leading first to the initial fluvial sedimentation. The whole succession between 903.5 and 914.2 m (parasequence VIa) is dominated by the medium-grained, trough cross bedded sandstones with plant detritus and local horizons with mud clasts. This succession (parasequence VIa) represents an initial deposition, probably in eroded valleys. Depositional system is interpreted as an alluvial (meandering river) or a coarse-grained deltaic (distributary channel) depositional subsystem. Above 903.5 m (transgressive surface), the sandstones are more fine-grained and the horizontal bedding and tabular cross bedding replace through cross bedding. Moreover, trace fossils (both domichnia and fodinichnia) appear in these strata. Based on these features, the complex between ~ 894.2 and 903.5 m (parasequence VIb) is interpreted as the nearshore (shoreface) facies followed by the lagoonal-embayment heteroliths, containing abundant plant fossils and fodinichnia burrows. The maximum flooding surface (897.2 m) is placed within these heteroliths. The age of depositional sequence VI still falls within the *Horstisporites planatus* megaspore zone (Marcinkiewicz, 1971), which points to the Late Sinemurian–Pliensbachian age. The prominent erosional base of this sequence is also regarded as the lower boundary of Komorowo Formation (Fig. 3).

DEPOSITIONAL SEQUENCE VII

The overlying sandstone strata (Fig. 64 CD, depth 879.0–895.5 m) are not preserved in the core material. Based on the neutron-gamma wire-logs and archival description, the sequence boundary can be tentatively placed at the depth of about 894.0 m. The overlying strata (860.0–879.0 m) are represented by homogenous, grey mudstones and lenticular heteroliths with siderite bands, pyrite concretions and fodinichnia burrows. Palynofacies point to an embayment-lagoonal depositional system with developing upward shallowing/isolation tendencies. The flooding surface at depth 860.0 m commences the parasequence VId deposits represented by wavy heterolithic-sandstone facies. These strata are characterised by numerous *Diplocraterion parallelum* Torell dwelling structures (Pl. IX, 4) and dinoflagellate cysts (Gedl, pers. comm.). The *Diplocraterion parallelum* Torell burrows show both the protrusive and retrusive character, even if occurring at the same horizon. This feature points to very unstable sedimentary conditions, i.e. rapid shifts from the erosion stages to rapid sedimentation periods (Pl. IX, 4). The unstable sedimentary conditions and other features (such as regular rhytmites observed in this section), may suggest that this section was deposited in a tide-influenced shore zone. The maximum flooding surface is associated with subtidal sandstones with hummocky cross stratification, while the heteroliths would represent a shallow subtidal/tidal flat environment. Presence of *Diplocraterion parallelum* Torell, foraminifera and Acritarcha points to a marine salinity, while palynofacies indicate rather nearshore–marginal marine (lagoonal) conditions. Collectively, it fits well the tidal interpretation. Subtidal sandstones would represent the maximum flooding surface of the whole depositional sequence VII.

Depositional sequence VII shows the increasing marine influences towards the top, therefore the highstand systems tract is thin (tidal plain deposits). The uppermost part of sequence VII could have been removed by erosion. A gradual development of the transgressive systems tract of sequence VII is associated with development of a barrier-lagoonal depositional system. Depositional sequence VII still falls within the *Horstisporites planatus* megaspore zone (Marcinkiewicz, 1971; Late Sinemurian–Pliensbachian age).

DEPOSITIONAL SEQUENCE VIII

The sequence boundary (Fig. 64 CD, depth 852.2 m) is associated with a sharp lithological contrast. The core interval between 848.3–852.2 m is poorly preserved, but it shows occurrence of coarser fraction (sandstones) and plant roots. This indicates an emersion (supertidal, probably delta plain environment).

The transgressive surface at the depth 848.3 m marks the beginning of sedimentation of wavy heteroliths with *Diplocraterion parallelum* Torell and fodinichnia burrows. Abundant dinoflagellate cysts (*Nannoceratopsis* spp.; Gedl, pers. comm) point to a marine environment, while other palynofacies features point to a proximity of shore or the type 2 palynological inversion, associated with storm activity. The overlying mudstones/claystones are grey in their lowermost part (839.7–842.7 m) and grey-greenish higher up in the profile (817.0–845.3 m). They contain typical offshore palynofacies, but sometimes features of marginal-marine palynofacies can be observed (depth 825.0–834.0 m). Such a "mixed" palynofacies characteristic is probably associated with the type 2 palynological inversion (storm events). Presence of foraminifera and quite numerous dinoflagellate cysts (mainly *Nannoceratopsis* spp.) points to the marine origin of this section. The maximum flooding surface was placed at the depth of 842.0 m, where the palynofacies show the most pronounced marine character. On the other hand, a general abundance of continental miospores indicates that the coastal plain was situated still not far away from the sedimentary basin. Presence of siderite bands and dispersed siderite, together with the lack of heteroliths and other wave-generated features, point to an isolation of the sedimentary basin. The characteristic greenish colour is caused by chlorite content. Estimation of the basin's depth at its maximum flooding stage (842.0 m), assuming that the 22 m of overlying HST sediments reflects approximately the accommodation space, points to a basin depth of about 35.0 m (assuming compaction factor of 1.6). It must have been an extensive basin of embayment character, showing many similarities to the recent Maracaibo Bay (Hyne *et al*., 1979). Perhaps the lowermost basinal sediments with foraminifera and offshore palynofacies (Fig. 64 CD, depth 839.7–842.7) were deposited in more open marine basin. The whole succession between 817.0–845.3 m represents the parasequence VIIIb and is topped with the palaeosol level with plant roots. Sandy facies with dolomitic cement occurring at the top of this parasequence are very thin and represent incipient, submerged barrier belts. The palaeosol level occurs in the claystones of similar character to those occurring in the deeper parts of the basin. It indicates that the wave energy in the sedimentary basin was weak. The shore zone of this basin was of a flat, muddy/marshy coastal plain character. It is yet another argument supporting the view that the whole basin of depositional sequence VIII was extensive but generally shallow.

The next parasequences VIIIc, VIIId and VIIIe represent recurred flooding-progradational successions, each one ending with marsh deposits. *Diplocraterion parallelum* Torell burrows occurring in the parasequence VIIId (depth 778.5 m) points to a short-lived marine water ingression, while the rest of sediments are typical of a shallow, lagoonal basin. In the middle part of the parasequence VIIIc one can find few strata with micro-hummocky cross lamination (Pl. V, 2) interpreted as tempestites, which points to periodically higher wave energy. However, for its most part the parasequence set VIIIc–e is dominated by the deltaic/coastal plain/marshy facies.

Depositional sequence VIII is of an Early Toarcian age, based on occurrence of megaspores *Minerisporites richardsoni* (Murray) Potonié and *Paxillitriletes phyllicus* (Murray) Hall & Nicolson (Marcinkiewicz, 1971). Finds of the dinoflagellate cysts (Gedl, pers. comm.) confirm this age. Depositional sequence VIII builds up the Ciechocinek Formation.

DEPOSITIONAL SEQUENCES IX AND X

The coarse-grained, in places conglomeratic lithofacies occurring between 756.5 and 767.2 m (Gorzów Wielkopolski IG 1, Fig. 64 CD) represent amalgamated alluvial deposits belonging to the Late Toarcian sequences IX and X and probably to the lowermost part of the next depositional sequence of a latest Toarcian or an early Middle Jurassic age. The sample taken from the mudstone intercalation at the depth of 761.3 m contains delta plain palynofacies, which points to the occurence facies separating the sequence IX from sequence X. Alluvial/deltaic sedimentation is characteristic for the final period of Late Toarcian sedimentation in the Polish Basin.

EARLY JURASSIC SEDIMENTATION IN THE POMERANIA REGION

Characterization of Early Jurassic sedimentation in this region (Fig. 1) is based on two boreholes: Mechowo IG 1 (Fig. 31 CD, fully cored) and Kamień Pomorski IG 1 borehole (Fig. 32 CD, with 30% of core, taken mostly from Sinemurian and Lower Pliensbachian deposits). The Mechowo IG 1 section is a full Early Jurassic profile (Dadlez, 1964a; Kopik, 1964; Marcinkiewicz, 1964) and in Kamień Pomorski IG 1 (Dadlez, 1972) the Toarcian section is lacking, except for the lowermost 18 m interval (of which only 1 m of core is preserved). Although it was only cored partially, the Chabowo IG 2 borehole (Fig. 1) yielded new ammonites representing the *margaritatus* Zone (Feldman-Olszewska, 1998; det. Kopik). Published data from other cores now lost or from partially cored boreholes was also taken in account (see the chapter "Previous works"). Continuous cored sections of Sinemurian deposits from Kamień Pomorski IG 1 borehole and Mechowo IG 1 borehole allowed presentation of a cross section showing the development of depositional systems and depositional sequences between these boreholes (Fig. 65).

DEPOSITIONAL SEQUENCE I

In the Mechowo IG 1 borehole (Fig. 31 CD) depositional sequence I begins with an erosional surface (depth 1130.0 m). Selection of that particular surface was based on bio-stratigraphical data — sediments below the surface contain the characteristic Late Triassic megaspore — *Trileites pinguis* (Harris) Potonié. In Pomerania, the underlying Rhaetian sediments are developed as alluvial (meandering river) depositional system (coal-bearing association), which closely resembles Early Jurassic alluvial facies. A similar situation occurs in Southern Sweden (Pieńkowski, 1991b). Consequently, in the Pomerania region, the lower boundary of the depositional sequence I is placed within alluvial deposits of Late and Middle Rhaetian–Hettangian age and recognition of depositional sequence I must be based solely on biostratigraphical criteria. As far as concerns lithostratigraphy, the whole sedimentary column between 1105.0 and 1200.0 m belongs to the same Zagaje Formation — therefore, this formation in Pomerania is much thicker and spans both the Rhaetian and Lower Hettangian deposits. The sediments below 1200.0 m already contain calcium carbonate (Dadlez, 1964a), which indicates transition to the arid climate and typical red-beds association. The same situation occurs in Southern Sweden (Scania), where the Höganäs Formation represents coal-bearing deposits of both Rhaetian and Hettangian age (Sivhed, 1984) overlying red-beds of Upper Triassic Kageröd Formation.

The lowermost part of the depositional sequence I (parasequence Ia, Fig. 31 CD, depth 1105.0–1130.0 m) contains the Hettangian–Early Sinemurian megaspore *Nathorstisporites hopliticus* Jung (Marcinkiewicz, 1971) and is developed as medium-grained, trough cross bedded sandstone representing entirely the alluvial (meandering channel–point bar) depositional subsystem. In Kamień Pomorski IG 1 (25 km to NW, depth 665.5–678.2 m, Fig. 32 CD), the grain size of sediments is significantly finer and overbank subsystems (floodplain, lacustrine and crevasse splays) dominate. Also the thickness of parasequence Ia is smaller at Kamień Pomorski IG 1. This indicates a substantial limitation of depositional energy of the alluvial palaeoenvironment, which probably reflects palaeoslope (Mechowo IG 1 was closer to the sedimentary source area situated to the East). Palynofacies from the Kamień Pomorski IG 1 borehole point to alluvial plain environment.

At the depth 1105.0 m at Mechowo IG 1 (Fig. 31 CD) a conspicuous transgressive surface occurs. The overlying sediments are represented by medium-grained to fine-grained sandstones with dolomitic cement, containing horizontal bedding, trough cross bedding and hummocky cross stratification. This complex (depth 1100.0–1105.0 m) is identified as being deposited within the shoreface-foreshore-barrier depositional subsystems. Transgression began with development of barrier-lagoon depositional system as the overlying mudstones (depth 1096.0–1100.0 m) show typical features of lagoonal/marsh sediments with palaeosol levels and horizons with abundant floral remains. The succession between 1096.0 and 1105.0 m, starting from shoreface deposits and passing into barrier/lagoonal deposits form parasequence Ib. There is conspicuous progradational trend in the upper part of the parasequence Ib. The transgressive surface at Kamień Pomorski IG 1 is not known as it is situated within the uncored section. It is tentatively placed at the depth 665.0 m.

Lagoonal deposits in the Mechowo IG 1 borehole (1096.0–1100.0 m) are overlain by wavy- and flaser dolomitic heteroliths with microhummocky cross lamination and foraminifera representing flooding stage (in this case the flooding surface is identified by a contact of dark, lagoonal deposits below with thin nearshore, basinal/offshore deposits above). Progradation in parasequence Ic (1087.5–1096.0 m) is again represented by succession of nearshore/barrier and lagoon depositional system, ending with marshy deposits with palaeosol and thin coal seams. At Kamień Pomorski IG 1 the parasequence Ic is of a similar character, but it shows more pronounced marine influence, reflected by thicker, more distal offshore deposits with abundant, diversified ichnofauna and marine palynomorphs.

The flooding surface of next parasequence (Id) at Kamień Pomorski IG 1 was studied in detail and it shows gradual character over 2 m of section (638.0–640.0 m). This gradual flooding event was associated with drowning of lagoon/marsh/delta-coastal plain depositional subsystems and shows short-lived substages of recurring flooding and reoccupation by a vegetation. This succession is also reflected in the palynofacies. Moreover, some minor fluctuations of palynofacies from lagoonal/interdistributary-delta plain environment, reflecting probably seasonal changes, were described from this section (Pl. III, 1). Nevertheless, the first conspicuous flooding event is identified with the flooding surface (Pl. IV, 3). This flooding event was associated with elevation of water table and changes in O_2 conditions in the sediment, resulting in pyritization of deeper plant roots (Pl. IV, 3). In Mechowo IG 1 the flooding surface is related to one-stage event of quick re-establishment of nearshore (offshore) depositional system with typical tempestites (Mechowo borehole, Fig. 31 CD, depth 1087 m). Further development of parasequence I d (Mechowo IG 1, depth 1062.5–1087.0 m) represents typical aggradational-progradational succession of a shoreface depositional subsystem ending with wave-reworked deltaic sediments. Development of parasequence Id in Kamień Pomorski IG 1 (Fig. 32 CD) was probably similar (a fragment of core from 627.0–628.0 m represents the shoreface depositional system), but lack of core does not allow any details to be determined.

Parasequence Ie (Fig. 31 CD, depth 1032.0–1062.5 m) shows a similar pattern to parasequence Id: flooding surface, offshore depositional subsystem with mudstones, dolomitic heteroliths and sandstones, trace fossils and tempestites passing into deposits of a prograding shoreface depositional subsystem.

The next parasequence (If) contains the maximum flooding surface of depositional sequence I (Fig. 31 CD, depth 1031.0 m), which occurs 1.5 m above the flooding surface (offshore mudstones with numerous but not diversified agglutinated foraminifera — *Crithionina* sp. (Kopik, 1964). The basin of the maximum flooding of sequence I was of restricted character (abundant, but not diversified foraminifera). Moreover, a conspicuous increase in boron content indicates elevated salinity, possibly close to a normal marine level. The character of the restriction causing ecological stress might have been poor oxygen conditions at the sea floor or immediately below it, which is supported by presence of dispersed siderite and pyrite concretions.

To sum up, the whole succession between 1031.0 and 1105.0 m (Fig. 31 CD) represents a transgressive systems tract of the depositional sequence I. The general "step-wise", retrogradational character of the TST is conspicuous, as well as its clear subdivision into five parasequences. Parasequences Ib and Ic represent nearshore–barrier/lagoon progradation during initial stage of the transgression, while parasequences Id, Ie and If represent further development of transgression with "classical", marine-type parasequences similar to the ideal parasequence model (Van Wagoner *et al*., 1990; Emery, Myers, 1996). Transgressive systems tracts of depositional sequence I in the Pomerania region (Mechowo IG 1 and Kamień Pomorski IG 1) can be well correlated into the Holy Cross Mts region. The number of parasequences is identical between the two regions, the only difference is that the transgressive surface in Pomerania region occurs earlier — at the base of the parasequence Ib, while in the Holy Cross Mts region it appears at the base of parasequence Ic (Figs. 24, 25, 28, 29). This is explained earlier in this work by a landward delay of transgression caused mainly by the sediment input and, to lesser extent, by a palaeoslope inclination (Fig. 26).

The higher part of the parasequence If (above the maximum flooding surface) commences the highstand systems tract (HST) of depositional sequence I. The progradational part of the parasequence is represented by shoreface–barrier-lagoon–foreshore-deltaic deposits.

An overlying thick package of sandstones with horizontal bedding and hummocky cross bedding (Fig. 31 CD, depth 947.0–1001.0 m) is interpreted as HST aggradational shoreface deposits, represented by parasequences Ig and Ih. Quick progradation resulted in development of deltaic depositional system and barrier-lagoon depositional system in the parasequences i, j and k (Fig. 31 CD, depth 926.0–947.0 m).

In the Kamień Pomorski IG 1 borehole (Fig. 32 CD, depth 522.5–637.0 m) parasequences Id, Ie, If, Ig and Ih were not cored, except for few fragments. By comparison with the Mechowo IG 1 borehole, it is possible that the maximum flooding surface occurs at depth 580.0–585.0 m. Slightly coarser sediments occurring between 510.0 and 522.5 m suggest the sequence boundary there, but characteristics of the overlying sediments points to its location higher in the profile. In that case, the section between 485.0 and 522.5 m represents the aggradational/progradational end of the sequence I, divided into three parasequences with flooding surfaces and development of regressive barrier-lagoon depositional system. Such interpretation is further confirmed by palynofacies and comparison with the Holy Cross Mts region, where faunistically documented, brackish-marine sediments are associated with a flooding surface occur in the parasequence Ik (Pl. XII, 5). Progradation of the parasequence Ik is terminated with emersion, evidenced by palaeosols and marsh deposits. At the same time in the Mechowo area, a deltaic depositional system developed (Fig. 31 CD, 947.0–1001.0 m).

According to previous work, megaspore (*Nathorstisporites hopliticus* Jung) and miospore (*Aratrisporites minimus* Schulz) finds, and sequence stratigraphic correlation, the whole depositional sequence I is of Hettangian age. The "pre-transgression" parasequence Ia (alluvial sediments) would belong to the Zagaje Formation, while the rest of sequence from the transgressive surface up represents nearshore–barrier/lagoon deposits of the Skłoby Formation.

DEPOSITIONAL SEQUENCE II

The sequence I/II boundary was identified at depth 926.0 m in Mechowo IG 1 borehole, where the overlying sandstones and mudstones with an abundant flora and palaeosol levels represents alluvial/delta-plain deposits. In the Kamień Pomorski IG 1 borehole, the sequence I/II boundary occurs at depth 485.0 m and is covered with a thin alluvial (meandering river channel) depositional system covered with delta plain deposits with a profuse flora and extensive palaeosol development and characteristic palynofacies (Fig. 32 CD; depth 476.0–485.0 m). The thickness of the parasequence IIa is much greater at Mechowo IG 1 (depth 892.5–926.0 m; Fig. 31 CD), which reflects higher subsidence and deposition rate. Erosion at the sequence I/II boundary was on rather a small scale and short lived in the Pomerania region.

The transgressive surface of the sequence II is associated with development of sandstones with dolomitic cementations deposited by the shoreface depositional subsystem in Mechowo IG 1 (depth 885.0–892.5 m) while in Kamień Pomorski IG 1 (depth 476.0 m, Fig. 32 CD) drowning of the delta plain area was very rapid — marshy deposits with palaeosol levels are covered immediately by offshore heteroliths. Further development of the sequence II in both boreholes (Mechowo IG 1, depth 839.0–892.5 m; Kamień Pomorski IG 1, depth 445.0–476.0 m) areas is similar — the nearshore (offshore) depositional system dominates. Two parasequences (IIb and IIc) are separated by a shallowing period with subordinate deltaic-lagoonal influences visible in palynofacies (Fig. 32 CD, depth 466.0 m). Emersions and palaeosols have not been found. The ensuing flooding surface of parasequence IIc is marked by the calcareous sandstone (Fig. 32 CD, depth 465,0 m). Marine or near-marine salinity of the transgreding sea is indicated by *Diplocraterion parallelum* Torell dwelling structures — they occur in parasequence IIc (Mechowo IG 1), where they are associated with elevated boron content. In both boreholes, the maximum flooding surface was found in the parasequence IIc, which is also consistent with the Holy Cross Mts region. The depositional sequence is terminated with emersion and palaeosol (marsh depositional subsystem) development in both boreholes, but apparently erosion was minimal.

The age of depositional sequence II still falls within the *Nathorstisporites hopliticus* megaspore zone (Hettangian– Early Sinemurian); it represents lower part of the Ostrowiec Formation.

DEPOSITIONAL SEQUENCE III

Erosion at the base of the sequence was rather insignificant, and the sequence boundary was marked by emersion and palaeosol (marsh depositional subsystem) development. Parasequence IIIa is built of marsh deposits.

The transgressive surface in both boreholes was associated with drowning of the marsh area and development of shoreface (Mechowo IG 1, depth 836.0 m, Fig. 31 CD) or embayment facies (Kamień Pomorski IG 1, depth 439.5 m, Fig. 32 CD). In both boreholes, parasequence IIIb is built mostly of nearshore heterolithic (partly calcareous) deposits (an offshore depositional subsystem), in places with chamosite ooids. Presence of *Diplocraterion parallelum* Torell in both boreholes indicates marine or nearly marine salinity. Lithofacies and palynofacies at Kamień Pomorski indicate slight isolation of the basin at the top of parasequence IIIb (lagoons and submerged shoals).

Overlying sandy shoal/barrier facies with carbonate cement and chamosite ooids mark the flooding surface and bottom of the parasequence IIIb in Kamień Pomorski IG 1 bore-

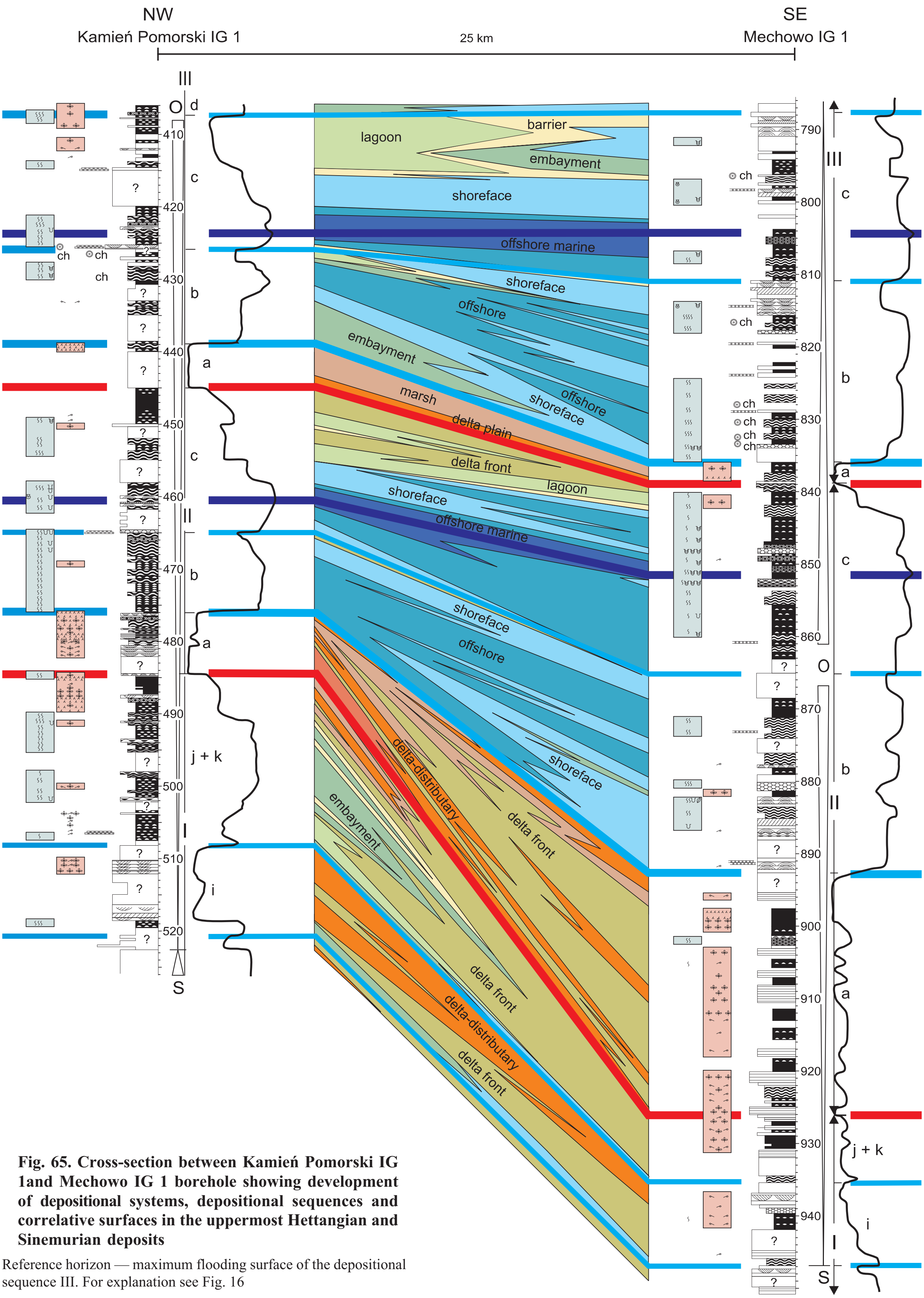

Fig. 65. Cross-section between Kamień Pomorski IG 1and Mechowo IG 1 borehole showing development of depositional systems, depositional sequences and correlative surfaces in the uppermost Hettangian and Sinemurian deposits

Reference horizon — maximum flooding surface of the depositional sequence III. For explanation see Fig. 16

hole (depth 425.0–426.0 m, Fig. 32 CD). Ensuing lenticular heteroliths with tempestites contain characteristic palynofacies with translucent amorphous organic matter of aquatic origin (AOMA) and dinoflagellate cysts. This level is regarded as a fully-marine interval and it occurs near the maximum flooding surface placed at depth 423.5 m (Fig. 32 CD). Similarly, in the Mechowo IG 1 borehole the same heterolithic interval (Fig. 31 CD, depth 797.0–811.0 m) is characterised by the presence of *Diplocraterion parallelum* Torell and the marine bivalve, *Tancredia* aff. *erdmanni* Lundgren (coll. et det. Kopik, 1964; - Pl. I, 12). According to Troedsson (1951), in southern Sweden this bivalve occurs only in the Sinemurian deposits. Kopik (1964) confirms such a stratigraphical position of *Tancredia erdmanni* Lundgren.

The next three parasequences (IIIc , IIId and IIIe) represent the nearshore depositional system, barrier-lagoon depositional system and wave-reworked delta depositional system. However, poor core recovery in this section made an exact lithofacies interpretation impossible, and this interval is interpreted only tentatively. In the Mechowo IG 1 borehole, where larger part of the uppermost part of the parasequence IIIe was cored, a conspicuous progradational/regressive succession occurs and the parasequence IIIe (and the whole depositional sequence III) with regressive lagoon/delta plain depositional systems (Fig. 31 CD, depth 750.2–757.0 m). The inference of a lagoon-embayment depositional system for the upper part of depositional sequence III is confirmed also in the Kamień Pomorski IG 1 borehole (Fig. 32 CD) where, in a heterolithic core fragment, (depth 350.0–352.0 m) characteristic embayment-lagoon palynofacies has been found.

Nearly complete core, representing the whole depositional sequence II and large section of the depositional sequence III, allowed construction of a cross section of Sinemurian deposits between Kamień Pomorski IG 1 and Mechowo IG 1 (Fig. 65). This shows the two-dimensional architecture of depositional systems and depositional sequences and parasequences. Subsidence and sedimentation rate must have been differentiated between the two boreholes, particularly at the end of Hettangian/ beginning of Sinemurian, when a local delta complex was developed from NE, affecting Mechowo area. The subsidence rate was higher in Mechowo IG 1 during at least Hettangian and Early Sinemurian times. Despite that, marine influences are equal or more pronounced at Kamień Pomorski IG 1, which was apparently closer to the marine basin. It shows, that the regional sea level changes and their consequences for the regional sedimentary development were largely independent of the local tectonic movements. It is worth mentioning that in the Wolin IG 1 borehole (20 km west of Kamień Pomorski IG 1) marine deposits with chamosite have been found. These represent the whole Sinemurian section, but more pronounced marine influences seem to occur in the Upper Sinemurian (Dadlez, 1975; Kopik, 1975). This section of marine origin would represent depositional sequence III.

Depositional sequence III, at least within parasequences IIIc–e, falls within the megaspore *Horstisporites planatus* zone (Late Sinemurian–Pliensbachian). In the Mechowo IG 1 borehole (Fig. 31 CD) megaspores are absent from the section of mainly marine character between the last appearance of *Nathorstisporites hopliticus* Jung (depth 863.0 m) and first appearance of *Horstisporites planatus* (Marcinkiewicz) Marcinkiewicz (depth 793.0 m). Presence of *Tancredia* aff. *erdmanni* Lundgren points to the Sinemurian age. Therefore, the depositional sequence III is likely of Late Sinemurian age. It belongs to the Ostrowiec Formation.

DEPOSITIONAL SEQUENCE IV

In the Mechowo IG 1 borehole (depth 750.2 m, Fig. 31 CD) the sequence boundary occurs in the cored section and is represented by a conspicuous erosion surface, covered with medium-grained, trough cross bedded sandstones with abundant plant remains. This lithofacies represents alluvial (meandering river) depositional system, which prograded onto underlying lagoon-marsh deposits of the uppermost depositional sequence III. At Mechowo IG 1, the alluvial depositional system is represented by a 30 m thick sedimentary package (depth 720.0–750.2 m), identified with the parasequence IVa. The overlying, 10 metre thick sandstone/mudstone package may represent delta plain deposits and it was included to the next parasequence IVb. Considerable thickness of alluvial/deltaic deposits suggests point to sedimentation in a river valley occurring in the Mechowo area. The thickness of possible initial alluvial/deltaic deposits (parasequence IVa) in Kamień Pomorski IG 1 borehole (depth 304.0–336.0 m, Fig. 32 CD) is at least 25 % lower, although this section was not cored and this interpretation is based only on the wire-line log data proving existence of more coarse intervals (sandstones) and on analogy with Mechowo IG 1 borehole.

Initial alluvial sediments of the parasequence IVa are followed by transgressive lagoonal sediments in Kamień Pomorski IG 1 borehole (depth 300.0 m, Fig. 32 CD). These may partly represent the time equivalent of deltaic sediments in Mechowo IG 1 (depth 710.0–720.0 m, Fig. 31 CD) — according to the rule of pre-transgression facies backstepping (Fig. 12), associated with locally higher sediment input and development of a delta depositional system. The transgressive surface in Mechowo IG 1 (depth 710.0 m) is very conspicuous and associated with ravinement and subsequent sedimentation of foreshore/shoreface deposits. In Kamień Pomorski IG 1 (depth 287.0 m), the flooding surface of parasequence IVb is associated with development of a transgressive lagoonal system with dinoflagellate cysts and lagoonal palynofacies.

The next flooding stage of parasequence IVc is associated with pronounced expansion of the marine basin. In Mechowo IG 1 (depth 675.0–691.0 m), initial nearshore cycles are developed, pointing to a locally higher sediment input. Marine conditions are evidenced by the presence of *Diplocraterion parallelum* Torell. In Kamień Pomorski IG 1 (depth 287.0 m), marine flooding was rapid and almost no shoreface facies were developed. The rapid transgression was caused by local palaeogeographical-hydrological conditions, as the Early Pliensbachian sea drowned the pre-existing lagoon area. Fully marine conditions were established over the whole Pomeranian region during sedimentation of the parasequence IV c. Marine sediments are of a considerable thickness (Mechowo IG 1, depth 607–675 m; Kamień Pomorski IG 1, depth 248.0–287.0 m).

Marine sediments (marine basin depositional system) are represented by grey, dark-grey, in places brownish, sideritic mudstones, claystones and shales with numerous pyrite concretions and characteristic *Chondrites–Palaeophycus* trace fossil assemblage (Pl. X, 3, 6–8). The range of this characteristic marine lithofacies extends at least as far as the Chabowo IG 2 borehole, which is situated beyond the Mid-Polish Trough (Fig. 1; Feldman-Olszewska, 1988). In Kamień Pomorski IG 1, the mudstones are more calcareous and are a marly lithofacies. The calcium carbonate component is lacking or rare in Mechowo IG 1, which likely is due to more acidic waters and relative proximity of a delta complex. Marine sediments contain a rich fauna, including ammonites, which allowed dating of this marine complex (parasequence IVc) to Early Pliensbachian *jamesoni* and *ibex* Zones (Kopik, 1964; Dadlez, 1972). The location of the maximum flooding surface was not an easy task, as the marine facies of *jamesoni–ibex* Zones are rather uniform. It was finally located in place where the palynofacies showed the most offshore, marine character (Kamień Pomorski IG 1, depth 256.0 m — *ibex* Zone) and within dark-grey mudstones with pyrite in the same biochronozone in Mechowo IG 1 (depth 626.5 m, few metres above *Acanthopleuroceras maugenesti* (d'Orbigny) location). Moreover, brownish claystones occurring at the depth of 256.7 m in Kamień Pomorski IG 1 (Fig. 32 CD) contain impoverished ichnofauna, reduced only to the shallow-penetrating *Chondrites* sp., which suggets oxygen-defficient bottom conditions (Bromley, Ekdale, 1984), in this case probably associated with deepening of the basin. Dadlez (1964a) placed the “maximum marinity level” somewhat deeper, within *jamesoni* Zone, as the foraminiferal assemblage was more diversified there. However, the diversity of marine benthos does not depend only on bathymetry. Moreover, deepest marine Pliensbachian sediments show that they were deposited under oxygen deficiency conditions (darker colours, abundant pyrite, occurrences of *Chondrites*), which could actually impoverish bottom fauna. In its uppermost part, the parasequence IVc shows shallowing trends, inferred from the palynofacies (Kamień Pomorski IG 1, depth 235.0–238.0 m). In Mechowo IG 1 (depth 603.8–606.3 m) this shallowing trend is indicated by impoverishment of marine fauna, admixture of silty/sandy fraction and more numerous plant detritus. These features show a restricted environment, probably of embayment-lagoon character.

The next, thin, sedimentary succession shows short-lived restoration of more marine conditions, indicated by palynofacies and presence of *Diplocraterion parallelum* Torell (Kamień Pomorski IG 1, depth 232.0–235.0 m) or by reappearance of calcareous foraminifera and increased boron content (Mechowo IG 1, depth 600.0–604.0 m). The overlying succession was not cored in Kamień Pomorski, but in Mechowo the uppermost 1 m of the mudstone package (Fig. 31 CD, depth 595.5–600.0 m) shows a slight shallowing (more numerous plant detritus), probably associated with progradation of a delta depositional system. This thin, muddy-heterolithic succession was distinguished as parase- quence IVd, based mainly on microfaunal, palynological and geochemical features.

Depositional sequence IV is faunistically-documented marine succession. It represents the most pronounced marine influence in the Early Jurassic basin in Poland. Fully-marine sediments are dated to *jamesoni–ibex* Zones (parasequence IVc, possibly parasequence IVd). The ammonite finds shows (Dadlez, Kopik, 1972), that the *polymorphus* Subzone is probably documented in Pomerania, presence of *taylori* Subzone is uncertain. Assuming rather considerable thickness of sediments below faunistically documented deposits of the Ibex biochronozone, one might conclude that the lowermost part of depositional sequence IV (part of parasequence IVa) could be of the latest Sinemurian age — late *raricostatum* Zone. Marine or restricted marine sedimentation would start from the *taylori* Subzone and transgressive surface (= flooding surface of the parasequence IVb) should be dated accordingly to the *taylori* Subzone. Some shallowing effects visible in Mechowo IG 1 (depth 678.0–687.0 m) could be tentatively dated to the *polymorphus–brevispina* Subzones. Depositional sequence IV forms the lower part of the Łobez Formation.

DEPOSITIONAL SEQUENCE V

At depth 599.0 m in Mechowo IG 1 borehole (Fig. 31 CD), the mudstone of parasequence IVd is covered by grey-pinkish, trough cross bedded sandstones with numerous plant detritus (depth 595.5–599.0 m). The lithofacies is typical of the delta depositional system (possibly delta front–distributary subsystems), indicating a fast delta progradation in the marine basin. The boundary between basinal — embayment mudstones of the parasequence Id and the prograding delta system (Mechowo IG 1, depth 599.0 m), is regarded as sequence boundary, and the sandy lithofacies of a delta depositional system represents parasequence Va.

Delta progradation in Mechowo IG 1 was rather short-lived. A prominent transgressive surface occurs at depth 595.5 m. The transgressive surface occurs within a sandstone package, but the change of sedimentary structures (appearance of hummocky cross stratification between 591.0 and 595.5 m) provides clear sedimentological clue defining the shoreface depositional subsystem. Moreover, presence of *Diplocraterion parallelum* Torell indicates return of marine salinity. The shoreface depositional subsystem represents the transgressive phase within parasequence Vb. An overlying mudstone package (depth 587.0–591.0 m) with numerous fodinichnia burrows in its is lower part represents the offshore depositional system with clear delta progradation above. This mudstone package seems probably represents the maximum flooding surface, but as the core recovery was poor for the rest of sequence V, this interpretation can only be tentative. Distinction of the next parasequences (depth 533.0–733.0 m) is also tentative. Occurrence of coarse-grained, partly conglomeratic sandstones, points to a high-energy, probably fluvial environment in Mechowo IG 1. On the other hand, the few cored intervals from the Kamień Pomorski IG 1 borehole (depth: 205.0–206.0, 178.0–182.0, 154.0–156.0, 139.0–143.5 m; Fig. 32 CD) show basinal heteroliths and, except for the lowermost section, they show palynofacies typical of a marine basin. This is also confirmed by presence of diversified foraminifera, marine bivalves and ichnofauna (including *Rosselia* sp. — Pl. IX, 8a, b), pointing to substantial facies differences of the depositional sequence V between Kamień Pomorski area, dominated by the marine basin depositional system (with some nearshore or lagoonal facies) and Mechowo area, dominated by the deltaic/marginal-marine facies. One should conclude, bearing in mind the pronounced marine or marginal-marine influences in the depositional sequence V which reached the Holy Cross Mts region, that the intensive sediment input and development of delta depositional system in Mechowo area is a local (regional — Pomeranian) phenomenon, possibly associated with tectonic rejuvenation of the north-eastern edge of the sedimentary basin. Such tectonically-induced fluctuations did not change the general sequence/parasequence arrangement, but it altered depositional systems, which in turn must dictate lithostratigraphic changes — the marine Łobez Formation embraces a much thicker section in Kamień Pomorski IG 1 (Fig. 32 CD) than in Mechowo IG 1 (Fig. 31 CD), where the marginal marine/deltaic Komorowo Formation replaces marine sediments for the majority of the profile of depositional sequence V. This sedimentary pattern was also observed by Dadlez (1969) and Dadlez and Kopik (1972).

Depositional sequence V lies between the documented *ibex* Zone deposits below and *margaritatus* Zone deposits above (Chabowo IG 2 borehole), therefore its age represents the *davoei* Zone. Together with depositional sequence IV it belongs to the marine Łobez Formation.

DEPOSITIONAL SEQUENCE VI

As in other regions in Poland, sedimentation of sequence VI was preceded by deep and extensive erosion. In the Mechowo IG 1 borehole (depth 533.0 m, Fig. 31 CD), an unknown portion of underlying heteroliths of parasequence Ve was eroded. Depositional sequence VI (parasequence VIa) commences with coarse, conglomeratic sediments indicative of the high-energy, alluvial (braided river) depositional system. The same boundary in Kamień Pomorski IG 1 (depth about 135.0 m, Fig. 32 CD), although it falls within poorly-cored section, shows rapid lithofacies contrasts and coarse-grained sediments above, indicating exposure of the basin and subaerial erosion. The whole parasequence VIa (Mechowo IG 1, depth 517.0–533.0 m; Kamień Pomorski IG 1, depth about 113.0–135.0 m) represents initial, coarse-grained alluvial deposition corresponding with the beginning of sea level rise. Alluvial (?deltaic) sandstone deposits extend far basinward — they occur in Wolin IG 1 borehole (1001.5–1011.0 m), in westernmost Pomerania (Dadlez, 1975), where the sandstone package separates underlying Early Pliensbachian marine deposits from overlying Late Pliensbachian marine deposits documented by ammonites (*spinatum* Zone, *apyrenum* Subzone). Thus the sea level fall at the base of depositional sequence VI was very widespread and pronounced. This sea-level fall caused formation of widespread coarse, alluvial facies separating the Lower Pliensbachian marine deposits from the similar Upper Pliensbachian deposits. Despite their close lithofacies similarity, merging the upper (Upper Pliensbachian marine package — Komorowo Formation) with lower (Lower Pliensbachian marine package — Łobez Formation) is not possible, at least within boundaries of Poland.

In both boreholes (Mechowo IG 1, depth 517.8 m; Kamień Pomorski IG 1, depth 117.7 m), alluvial deposits are replaced by marginal-marine or marine deposits, which represent the ensuing transgression. In Mechowo, the transgressive surface is rather inconspicuous, as the deltaic deposits with pyrite concretions replace those of the alluvial depositional system. At Kamień Pomorski, the transgressive deposits represent the offshore depositional subsystem (indicated by palynofacies).

Further useful data were obtained from the Chabowo IG 2 borehole (Feldman-Olszewska, 1988). Although the borehole (see Fig. 1 for its locality) was only cored partially, it yielded important ammonite fossils allowing more precise dating of the Upper Pliensbachian deposits. In this borehole (at a depth of about 960.0 m), *Amaltheus* (?*Proamaltheus*) cf. *wertheri* Lange has been found (Feldman-Olszewska,1997; det. Kopik), indicative of the *margaritatus* Zone. It is not clear if this ammonite belongs to the sequence VI or VII, both representing the *margaritatus* Zone. However, it is more likely that this find is within the sequence VI, as this sequence spans most of the *margaritatus* Zone (Hesselbo, Jenkyns, 1998). Moreover, the uppermost *gibbosus* Subzone of *margaritatus* Zone probably coincides with the sequence VI/VII boundary and related hiatus or alluvial sedimentation.

Depositional sequence VI is characterised by the rapid sea level fall at its base and a following rapid transgression, which restored sedimentation over Pomerania region and the Mid-Polish Trough. The age of depositional sequence VI is earliest Late Pliensbachian (*stokesi*–*subnodosus* subzones of *margaritatus* Zone). It belongs to the lowermost part of the Komorowo Formation.

DEPOSITIONAL SEQUENCE VII

Depositional sequence VII is again preceded by erosion (Mechowo IG 1, depth 515.2 m, Fig. 31 CD). In Kamień Pomorski IG 1 (non-cored section, Fig. 32 CD) the erosion surface is inferred at the depth of about 107.0 m. Sharp contrast between medium-grained, in places conglomeratic, trough cross bedded sandstones above the erosion surface (sequence boundary) and underlying mudstones of parasequence VIb shows that unknown portions of sediment were eroded. Sedimentation of the depositional sequence VII in the Mechowo IG 1 (depth 492.0–515.0 m) commenced with variable grain-size, trough cross bedded sandstones with abundant plant remains (parasequence VIIa) and pressumably the upper part of deposits of sequence VI were eroded. In the Kamień Pomorski IG 1 (depth 93.5–107.0 m), the same parasequence is represented by finer sediments, not coarser than fine-grained sandstones, as evidenced by the cutting samples. In the uppermost part, brownish mudstones with lenticular lamination and plant roots occur — they represent marsh depositional system. In the Mechowo IG 1, the alluvial depositional system (depth

492.0–515.0 m) is topped by a thin coal seam, representing a palaeosol. Overlying parasequences VIIb and VIIc at Mechowo are represented by the deltaic depositional system, although poor core recovery does not allow a detailed interpretation. Relatively high boron content in a mudstone sample taken from a depth of 481.0 m (Fig. 31 CD) indicates a more pronounced marine influence. Marine influences in Kamień Pomorski IG 1 (depth 91.0–93.0, 65.0–67.5 m) are evidenced by marine to lagoonal palynofacies with dinoflagellate cysts. Collectively, the data show the upper part of depositional sequence VII was deposited in marine and marginal-marine environments (nearshore, barrier-lagoon and deltaic depositional systems). Nearshore, subordinately barrier-lagoon depo- sitional systems prevailed at Kamień Pomorski IG 1 (Fig, 65), while in the Mechowo area deltaic depositional system dominated.

In the Wolin IG 1 borehole, situated 20 km to the west of Kamień Pomorski borehole (Fig. 1), an ammonite fauna representing the *spinatum* Zone (*apyrenum* Subzone) has been found (Dadlez, 1975; Kopik, 1975). The whole Wolin profile shows pronounced marine character, particularly in Sinemurian and Pliensbachian sections. Marine to marginal marine deposits from depositional sequence VII of Kamień Pomorski IG 1 borehole would be an equivalent of the ammonite-bearing strata from Wolin and they would represent the early *spinatum* Zone age.

Ammonite dating shows, that the thickness fluctuations between Kamień Pomorski IG 1 and Wolin IG 1 are significant: in Kamień Pomorski IG 1 and in Mechowo IG 1 combined sequences IV and V are twice as thick as in Wolin IG 1, while the sequence VII in Wolin is approximately 2.5 times thicker than in Kamień Pomorski and in Mechowo. Such differences in a distance of 20 km can be explained by local, synsedimentary tectonics — this part of Pomerania region is intersected by number of faults (Dadlez, Kopik, 1972). The Wolin IG 1 borehole is situated within Świnoujście dislocation zone, while Kamień Pomorski IG 1 is situated close to the edge of the Kamień dislocation zone (Dadlez, Kopik, 1972). Besides the thickness of deposits, synsedimentary tectonics could influence also lithofacies and depositional system development. The overprint of regional sea level changes is however still "readable". Depositional sequence VII belongs to the Komorowo Formation.

DEPOSITIONAL SEQUENCE VIII

In the Kamień Pomorski IG 1 borehole (depth 24.0–57.5 m, Fig. 32 CD), this sequence is represented only in a fragmentary fashion in the non-cored section. Its base is marked by coarse, conglomeratic sandstones at depth 58.0 m. This represents an erosion and sequence boundary. In the Mechowo IG 1 borehole, between 408.5 and 456.0 m, the core recovery was poor. The sequence boundary was tentatively placed at depth 456.0 m, where coarse-grained sandstones with quartz pebbles and mud clasts point to erosion and high-energy, alluvial environment. The position of the sequence boundary means that the overlying alluvial/deltaic sediments (408.5–456.0 m) would belong to parasequence VIIIa, representing initial, pre-transgression alluvial/deltaic succession. It is possible, however, that the sequence boundary is situated higher — for example at 434.0 m.

A transgressive surface in Kamień Pomorski IG 1 at depth 42.0 m, at the bottom of a continuous mudstone complex (1 m of core with greenish-grey mudstone with lenticular lamination was taken from basal part of the complex). This complex ends the Lower Jurassic section in the Kamień Pomorski IG 1 borehole. In the Mechowo IG 1 borehole, at depth 407.0–408.5 m, reworked shoreface sandstones indicate the establishment of a nearshore depositional system. These deposits are followed by basinal facies — grey mudstones with lenticular lamination. The lowermost section (Fig. 31 CD, depth 405.0–407.0 m) contains drifted plant fossils and even thin coal accumulation (possibly drifted logs), which points to a semi-closed basin of embayment-lagoon character. The following section (depth 370.0–405.0 m) represent uniform grey and brownish-grey mudstones, in places with lenticular lamination. Pyrite nodules are common; biogenic structures (only fodinichnia) are rare. An arenaceous foraminiferal assemblage, which is impoverished in number of genera but rich in number of individuals, occurs in the whole complex and boron content is conspicuously elevated. This complex is interpreted as a marine basin (offshore depositional system). The poor diversity and highdominance character of foraminiferal assemblage may be associated not with lowered salinity or bathymetry, but rather with oxygen deficiency at the sea floor. The offshore mudstones are followed by progradational succession (depth 360.2–370.0 m) of shoreface heteroliths and sandstones. Presence of *Diplocraterion parallelum* Torell indicates marine or near-marine salinity. The whole succession between transgres- sive surface and top of the shoreface-prograding succession (depth 360.2–408.5 m) represents parasequence VIIIb. The maximum flooding surface of the whole depositional sequence VIII is inferred at depth 384.0 m.

The next flooding surface occurs at a depth of 360.2 m. This commences deposition of parasequence VIIIc. In this parasequence, the basinal mudstones (Fig. 31 CD, depth 341.3–360.2 m) have typical greenish-grey colour of the Ciechocinek Formation (Pl. IV, 4). In the lower part there are tempestite intercalations and the mudstone complex contains quite diversified foraminiferal assemblages, including calcareous and agglutinated forms (Dadlez, 1964a). In its upper part (depth 341.3–348.0 m), the same mudstone complex shows features of decreasing salinity – foraminifera fauna disappear and dispersed plant detritus occur. The overlying thick sandstone complex (depth 308.5–341.3 m) represents prograding nearshore, barrier or deltaic depositional systems. The deltaic depositional system dominates in the uppermost four metres, indicated by relatively more numerous plant detritus, coaly particles and abundant muscovite. More precise determination of the remaining part of this complex is difficult because of the poor core recovery.

The next flooding surface (Fig. 31 CD, depth 308.5 m) restores the barrier-lagoonal depositional system with characteristic greenish-grey mudstones (depth 301.7–308.5 m), decreasing-upward boron content and an overlying sandstone-siltstone complex (298.5–301.7 m) representing submerged barrier-backbarrier environment, with plant roots in its upper part. Above that barrier-backbarrier complex, lagoon-marsh depositional subsystem is developed — greenish-brownish mudstones with siderites, remains of Phyllopoda and palaeosol levels. The progradational succession between 298.5 and 308.5 m represents parasequence VIIId.

The marsh area was then drowned again (lagoon-marsh depositional subsystem is replaced by very shallow lagoon with numerous plant remains — depth 291.2–298.5 m). This flooding is associated with the last parasequence of depositional sequence VIII (parasequence VIIIe). The preserved fragment of the parasequence VIIIe shows a slight deepening upward tendency and is abruptly truncated at the top due to subsequent erosion, which removed an unknown portion of sediment including upper, retrogradational succession of this parasequence.

Depositional sequence VIII is of Toarcian age, as evidenced by continuous, abundant occurrences of *Paxillitriletes phyllicus* megaspore association with *Minerisporites richardsoni* (Murray) Potonié (Marcinkiewicz, 1971). The stratigraphical position of the grey mudstone complex between 370.0 and 407.0 m needs some comment. Dadlez (1964a) assigned this complex to the Upper Pliensbachian Komorowo beds, changing his own, previous interpretation (Dadlez, 1957, 1958). The main argument for the change was his concept of cyclical division of the Early Jurassic deposits — he believed, that the heterolithic-sandstone complex between 360.2 and 370.0 m commenced a transgressive cycle. In my opinion, the transgressive systems tract of depositional sequence VIII commences at the depth 408.5 m. Consequently, the grey mudstone complex between 370.0 and 401.0 m actually represents the maximum extension phase of the Early Toarcian basin in the Pomerania region. Therefore, I prefer the original concept of Dadlez (1957; 1958). However, the most important argument against assigning this complex to the Late Pliensbachian, is based on biostratigraphical clues — these strata are characterised by fairly rich, continuous occurrence of the megaspore *Paxillitriletes phyllicus* (Murray) Hall & Nicolson and first appearance of *Triletes sparassis* Murray. Although Marcinkiewicz (1964) reluctantly accepted the new boundary of the Toarcian proposed by Dadlez (1964a), she claimed that the Toarcian deposits are characterised by continuous occurrences of *Paxillitriletes phyllicus* and *Triletes sparassis* Murray (Marcinkiewicz, 1962; 1964). Thus, the Marcinkiewicz's opinion is (her pers. comm.) that the lower boundary of Toarcian in Mechowo IG 1 borehole should be situated at the 480.0 m, in accordance with the view of the present author.

Another argument is the position of the maximum flooding surface. The lower part of overlying greenish-grey mudstone complex between 341.2 and 360.2 m contains quite diversified foraminifera fauna, indicating marine conditions, while the upper part is of lagoonal character — without apparent lithofacies contrast. On the basis of diversity of foraminiferal assemblages, one could conclude that the maximum marine influence (and maximum flooding surface) would be somewhere between 347.0 and 357.0 m. On the other hand, the complex between 370.0 and 405.0 m shows conspicuously higher boron content and abundant pyrite concretions and number of foraminifera individuals is higher. Moreover, in the Gorzów Wielkopolski IG 1 borehole (depth 840.0–847.0 m, Fig. 64 CD) analogous grey mudstones represent the most basinal, offshore palynofacies. This complex certainly represents a restricted, stressed environment, but the stress factor was not salinity — it was oxygen deficiency. Therefore, the parasequence VIIIb is regarded as this one containing maximum flooding surface despite the low-diversity microfauna.

On the basis of these facts, the depositional sequence VIII represents an Early Toarcian deposit, with pronounced, nearly equal marine influences in parasequences VIIIb and VIIIc, diminishing up through the section. Sedimentation of parasequences VIIIb and VIIIc was separated by a shallowing event. Depositional sequence VIII corresponds with the Ciechocinek Formation, except in its lowermost part (parasequence VIIIa).

DEPOSITIONAL SEQUENCE IX

The sequence begins with an erosional surface (Mechowo IG 1, depth 291.2 m, Fig. 31 CD). Sedimentation begins with medium- to fine-grained sandstones with trough cross bedding and horizontal bedding, assigned to the alluvial channel — distributary channel depositional subsystems (parasequence IXa, depth 276.5–291.2 m).

The overlying sediments (depth 237.0–276.5 m) have a much larger share of mudstone and heterolithic lithofacies. This points to a rise in base level, but it is not clear whether they represent alluvial floodplain deposits, delta plain deposits or, at least for some heterolithic parts, delta-front deposits. The presence of coarsening-upwards cycles as well as slightly elevated boron content suggest that the deltaic depositional system dominated between 237.0–276.5 m (parasequence IXb), but this interpretation is tentative, particularly for the section with poor core recovery.

Depositional sequence IX falls within the *Paxillitriletes phyllicus* megaspore zone and consequently is of Toarcian (most likely Late Toarcian) age. It belongs to the Borucice Formation.

DEPOSITIONAL SEQUENCE X

This depositional sequence is tentatively indicated as a thin sedimentary package of coarse alluvial sediments resting on the erosional surface (Mechowo IG 1, depth 232.5–236.0 m, Fig. 31 CD) and topped with a thin mudstone bed with the *Paxillitriletes phyllicus* (Murray) Hall & Nicolson megaspore. It is of Late Toarcian age and belongs to the Borucice Formation.

The lowermost part of the next depositional sequence commences Middle Jurassic sedimentation. It is represented by coarse alluvial deposits, overlying an erosional surface (depth

228.0–232.5 m). In its lowermost part this succession may still be latest Toarcian age, but it is only a hypothetical assumption. The overlying, very conspicuous erosion surface (depth 228.0 m) represents ravinement (strand line) marked with a conglomeratic bed — the effect of reworking of the underlying sediments by the transgressing sea. This is the transgressive surface of the next depositional sequence, associated with the Middle Jurassic, probably Aalenian, deposits.

* * *

Determination of the Early Jurassic depositional history in the Pomerania region (supported by the biostratigraphical data — Fig. 2) gives an opportunity for comparison with other West European basins. Through well-dated marine sediments in Western Europe, correlation with the Exxon eustatic curve (Haq *et al*., 1987), other regional relative sea level curves (Hesselbo, Jenkyns, 1998; Nielsen, 2003) and the time scale (Gradstein *et al*., 1995) could be attempted, detailed in the following chapters of the present work. In Pomerania region, marine depositional systems existed in the Early and Late Sinemurian, in the Pliensbachian, and in the Early Toarcian. In the Middle Hettangian the basin was probably of almost marine salinity. The thus well-defined sequences and parasequences could then be compared with the other regions: Fore-Sudetic Monocline, Wielkopolska region and Holy Cross Mts region. Using sections with full core recovery, it is possible to present detailed development of most of the Sinemurian deposits in the region. The Pomerania region was subjected to synsedimentary tectonic activity, which resulted in variable thicknesses of Early Jurassic deposits (particularly in Pliensbachian times). The "overprint" of regional sea level changes is yet still readable and overwhelming any local tectonics (Fig. 65).

Based on the regional sequence development in Pomerania region (supported by the ammonite dating and other biostratigraphical data) and the mentioned comparison with other sea level curves, reduction in the size of the basin occurred possibly in the latest Hettangian (latest *angulata* Zone), Late Sinemurian (early *obtusum* Zone), latest Sinemurian (mid-*raricostatum* Zone), disputably late Early Pliensbachian (latest *ibex* Zone), earliest Late Pliensbachian (transition between latest *davoei* and earliest *margaritatus* Zone), mid-Late Pliensbachian (late *margaritatus* Zone), latest Pliensbachian (late *spinatum* Zone), mid-Toarcian (early *variabilis* Zone), Late Toarcian (mid-*thouarsense* Zone, latest Toarcian (late *levesquei* Zone).

Increase in the basin extent occurred in the Middle Hettangian (mid-*liasicus* Zone), Early Sinemurian (mid-*semicostatum* Zone), mid-Late Sinemurian (early *oxynotum* Zone), Early Pliensbachian (beginning of *ibex* Zone), latest Early Pliensbachian (mid-*davoei* Zone), early Late Pliensbachian (early *margaritatus* Zone), Late Pliensbachian (early *spinatum* Zone), Early Toarcian (*tenuicostatum* Zone) and disputably in the late Middle Toarcian (mid-*variabilis* Zone) and late Toarcian (late *thouarsense* Zone).

Moreover, similar sequence development in the Holy Cross Mts (Fig. 48) suggests that this pattern may be extended over the whole Polish Basin.

EARLY JURASSIC SEDIMENTATION IN THE MAZURY REGION (PART OF THE BALTIC SYNECLISE)

The Baltic Syneclise is situated in the North-Eastern Poland (Fig. 1). Development of Early Jurassic deposition was recognised in one fully cored borehole Bartoszyce IG 1 (Fig. 66 CD). This region is situated far beyond the Mid-Polish Trough, and consequently, the Early Jurassic deposits are strongly reduced in their thickness. Hettangian and Sinemurian deposits are lacking, similarly to the Częstochowa region. Lithostratigraphical characteristic of the Bartoszyce IG 1 borehole was given by Dadlez (1974). This characteristic was supplemented by petrographical studies performed by Maliszewska (1974).

DEPOSITIONAL SEQUENCE IV

The Early Jurassic sedimentation in the Baltic Syneclise followed a long erosion/non-depositional period, extending from the Rhaetian (Bartoszyce beds — age confirmed by megaspores — Dadlez, 1974) to Pliensbachian. According to Dadlez (1974), the Early Jurassic deposits in Bartoszyce IG 1 borehole cannot be older than Sinemurian, because they contain megaspore *Erlansonisporites reticulatus* (Zernt) Marcinkiewicz, which does not occur in Hettangian. In the previous work, the oldest Early Jurassic deposits in the Baltic Syneclise have been tentatively assigned to the Late Pliensbachian (Dadlez, 1974; Šimkevičius, 1998). In the present work, the sedimentary succession between 735.0 and 821.0 m is assigned to both the Early and Late Pliensbachian, based on the sequence stratigraphic correlation. It is possible that the Pliensbachian sedimentation was preceded by recurrent sedimentation–erosion periods in the Hettangian–Sinemurian times, but due to the lack of any Hettangian and Sinemurian sediments in the Baltic Syneclise this is only a hypothetical assumption.

The erosional surface at the depth of about 821,0 m represents the sequence boundary (the position of this boundary is based on the archival description because this core interval is poorly preserved). The sequence boundary is overlain by coarse-grained sediments — conglomerates and coarse/medium-grained sandstones (Fig. 66 CD, depth 817.0–821.0 m). Recognition of sedimentary structures is difficult because of a poorly preserved core, but coarse-

-grained, poorly-sorted sediiments are indicative of alluvial deposits, possibly representing braided or/and meandering river facies.

The core interval between 814.5 and 817.0 m is also poorly preserved. It represents sandstone lithofacies (with two horizons containing mud clasts) and mudstone lithofacies. A sample taken from the mudstone lithofacies contains palynofacies characteristic of lagoonal deposits (presence of Acritarcha), thus indicating a brackish marine-marine transgression reaching the Baltic Syneclise. This basin was probably of an embayment character. The basin must have formed a wide branch of the Early Pliensbachian marine basin in Poland extending from the Mid-Polish Trough to the northeastern Poland (Fig. 1) as there is no other possible way of a marine influence. The transgressive surface is inferred at the depth 817.0 m. Themaximum flooding surface is represented by the mudstone bed with brackish-marine palynofacies (Fig. 66 CD, depth 816.1 m).

Effects of the brackish marine transgression must have been lasting for some time and the following sedimentary succession (depth 808.0–814.5 m) was likely deposited in a delta plain gradually passing into alluvial plain, as shown by palynofacies. Sediments above 808 m show features typical of meandering river depositional system. Numerous fining-upward sedimentary cycles reflect autocyclic sedimentation processes, associated with the lateral migration of channels (thicker cycles) or crevasse splay development (thinner cycles with erosional bases). The overbank mudstone litho- facies with abundant plant fossils and palaeosol horizons account for considerable part of this interval (depth 800.2–814.7 m). Palynofacies contain abundant phytoclasts. Interestingly, the bisaccate pollen grains are significantly more frequent than spores and the spore/pollen ratio is pretty stable through the profile. It shows that the surrounding vegetation was dominated by a coniferous (gymnosperms) forest and the low-standing vegetation characteristic of a swampy environment and a high water table was of a lesser extent.

DEPOSITIONAL SEQUENCE V

The erosional surface at depth 800.2 m (Fig. 66 CD) commences a new sedimentary succession of different character. The fine-grained, overbank deposits are rare (except for the uppermost 3 m) and the whole succession (depth 778.2–800.2 m) is dominated by sandstones. This core interval is poorly preserved, but in places trough cross bedding can be observed. The whole succession is interpreted as alluvial (meandering river) depositional system, dominated by a channel subsystem.

DEPOSITIONAL SEQUENCES VI AND VII

The erosional surface at depth 778.2 m (Fig. 66 CD), overlain by the 50 cm thick bed of quartz conglomerate and sandstone, represents an important boundary separating facies of two different petrographical provenances. The depositional sequences VI and VII (depth 738.2–778.2 m) differ from the underlying depositional sequences IV and V. Relevant data were provided by Maliszewska (1974, p. 285, her table 29), although her information was overlooked in further interpretations. The data show some radical changes in accessory mineral composition (Fig. 66 CD):

— garnet is totally absent from the samples between 782.5 and 813.7 (sequences IV and V), while in the samples taken from the interval between 741.0 and 765.8 m (sequences VI and VII) garnet is by far the most frequent translucent accessory mineral

— zircon and tourmaline are much more frequent in the interval between 782.5 and 813.7 m than in the interval between 741.0 and 765.8 m

— rutile is much more frequent in the interval between 741.0 and 765.8 m than in the interval between 782.5 and 813.7 m

— epidote does not occur in the samples between 782.5 and 813.7 m, while it does occur in samples from the interval between 750.0 and 757.0 m

These differences were certainly associated with different petrographical composition of the sediment source areas. The general palaeogeographical situation in NE Poland and directions of sediment transport does not show any significant changes in the Pliensbachian times — the Belorussian massive (the Mazury-Belorussian anteclise; Fig. 1) provided a stable sediment source area (Maliszewska, 1967, 1974; Dadlez, 1974). Thus, the rapid and prominent change of sediment provenance must have been associated either with the grooving/retrogressive erosion in the sedimentary source area caused by a rapid fall of base level in sedimentary basin, or a tectonic uplift in the sediment source area. As the second factor lacks any evidence, the base level fall seems to be the most probable explanation. The appearance of epidote is noticeable, as this mineral is relatively less stable than the garnet, zircon, tourmaline and rutile. Thus it is rather unlikely that the epidote comes from older sedimentary rocks. This mineral was probably delivered from exposed crystalline rocks. This exposure was probably associated with deeper erosion caused by the base level fall. Consequently, deposition of the sequence VI was preceded by a widespread erosion marking a prominent bounding surface separating sandstones of different provenance.

The depositional sequences VI and VII are built up of grey, medium- to coarse-grained sandstones (in places conglomeratic), with plant fossils or coaly detritus. Generally, trough cross bedding sets dominate in these sequences, although poorly preserved core does not allow more detailed observation. The lithofacies are interpreted as deposits of an alluvial — braided channel depositional subsystem (overbank mudstones are very rare). A single occurrence of mudstone interval (758.5–759.5 m) represents probably overbank deposits, ending the depositional sequence VI. The erosional surface above these mudstones, followed by sandstones with mud clasts, is interpreted as the base of depositional sequence VII.

Depositional sequences VI and VII are thought to be of a Late Pliensbachian age, based on sequence stratigraphic correlation. The base of depositional sequence VI can be correlated with the most conspicuous Early Jurassic fall of sea level in the Polish Basin.

Depositional sequences IV, V, VI and VII are dominated by the alluvial deposits (except for a thin bed representing marine embayment facies — Fig. 66 CD, depth 814.5–817.0 m). These sequences are assigned after Dadlez (1968, 1974) to the Olsztyn Formation.

DEPOSITIONAL SEQUENCE VIII

The depositional sequence VIII commences with an erosional surface marked with coarse-grained sediments (Fig. 66 CD, depth 735.5–738.5 — parasequence VIIIa). The transgression surface occurs at depth 735.5 m, where sandstones show features of reworking by the transgression. The transgressive sediments are followed by greenish-grey mudstones, heteroliths and fine-grained sandstones with abundant plant fossils and plant roots (depth 727.0–734.5 m) representing a local delta progradation (delta plain–interdistributary bay–crevasse deposits). The greenish-grey heteroliths occurring between 725.0 m and 727.0 m contain specific palynofacies — number of miospores is extremely high (almost 2500 specimen in one sample). This exceptionally high number of miospores indicates their local concentration. Likely it was connected with a rapidly decelerating fluvial flow in a delta-fringing lagoon forming a "hydrodynamic trap". Miospores were delivered by a nearby distributary channel into an isolated and shallow lagoon/interdistributary bay and they were not redistributed by the basinal processes due to a low-energy of wave and currents.

Deeper facies (heteroliths with some calcareous ooids) occur at depth 723.8–725.0 m; the maximum flooding surface occurs at the depth of 724.2 m (Fig. 66 CD). Marine influences are indicated by the palynofacies (Acritarcha are present). The overlying interval between 721.5 and 723.8 m represents a marsh depositional subsystem with numerous palaeosol levels. The succession between 721.5 and 735.5 m represents the parasequence VIIIb, showing a gradual upward deepening of facies, characteristic of the type-1 marginal-marine parasequences (Fig. 26).

The next flooding surface (721.5 m) commences sedimentation of brackish-marine embayment deposits. These facies are represented by the greenish-grey heteroliths and fine-grained calcareous sandstones with microhummocky cross-lamination, domichnia dwelling structures, storm cycles with characteristic spill-over wave ripples at the top (Pl. IV, 6; see Fig. 7) and wave ripples with characteristic chevron-like lamina (Pl. V, 7). The embayment deposits are thin and they are overlain by lagoon-marsh facies with numerous plant roots and palaeosol levels, ending the succession (Fig. 66 CD, depth 710.5–720.0 m). The succession between 710.5 and 721.5 m represents parasequence VIIIc.

Palynofacies confirm that the sedimentary basin of depositional sequence VIII in the Baltic Syneclise was shallow and isolated. This basin was surrounded by a flat coastal/delta plain with marshes, delivering abundant spores and phytoclasts. Marine influences are documented by palynofacies with sparse Acritarcha and occasionally by presence of the lighter amorphous organic matter of aquatic origin (AOMA).

DEPOSITIONAL SEQUENCES IX AND X

The succession between 702.0 and 710.5 m (Fig. 66 CD) is represented by sandstones. The core is poorly preserved and only in few places some additional features (plant fossils and trough cross bedding sets) can be observed. These sandstones represent alluvial facies of meandering or braided river depositional system and are assigned to the depositional sequence IX or X (or both of them). The mudstones between 700.0 and 702.0 m represent lagoonal deposits with dinoflagellate cysts and are probably of a Middle Jurassic age. In Poland, Toarcian deposits of the sequences IX and X are represented by alluvial, subordinately deltaic deposits, thus it is unlikely that the Late Toarcian embayment/lagoonal deposits would occur so far away from the Mid-Polish Trough. Presence of megaspore *Paxillitriletes phyllicus* (Murray) Hall & Nicolson does not contradict the Middle Jurassic age of these strata, as this megaspore occasionally occurs in the lowermost Middle Jurassic deposits (Marcinkiewicz, 1962, 1964).

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The Early Jurassic sedimentation in the Baltic Syneclise, similarly to that of the Częstochowa region, shows depositional architecture typical of marginal parts of the sedimentary basin (Fig. 67). The thickness of the Lower Jurassic sediments is much thinner than in the Mid-Polish Trough and Hettangian and Sinemurian deposits are lacking. The marine/brackish marine facies discovered in Lower Pliensbachian in the Baltic Syneclise point to a wide extent of the Early Pliensbachian transgression. The boundary between Lower and Late Pliensbachian is associated with a major erosional event and change of petrographical provenance. Presence of the grey-greenish mudstone-heterolithic lithofacies of the Early Toarcian age confirm that at that time this lithofacies was widely extended over the whole Polish Basin (Fig. 67). The occurrence of marginal-marine deposits far from the Mid-Polish Trough indicates that the area between the Mid-Polish Trough and Baltic Syneclise was generally of a lowland character. This was conductive for the north-easterly development of marine transgressions, along a way called herein the "Mazury Embayment". Sequence stratigraphic correlation allows distinguishing of both Lower and Upper Pliensbachian deposits and modification of the upper boundary of Early Jurassic deposits in this region. Accordingly, the lithostratigraphy of Jurassic deposits in the south-eastern Baltic area (Šimkevicius, 1998; Feldman-Olszewska, 1998), should be amended. The major part of the Neringa Formation would be of an Early Pliensbachian age. It is worth mentioning, that any marine transgression in the Baltic Syneclise could develop only from the Mid-Polish Trough, as there was no alternative way (Šimkevicius, 1998).

LITHOSTRATIGRAPHY OF THE EPICONTINENTAL LOWER JURASSIC DEPOSITS IN THE POLISH BASIN

As it was mentioned in the first chapter, in the previous works there were no clear and unified criteria in naming new lithostratigraphical units. Therefore, one of the scopes of the present paper is introduction of newly defined lithostrati- graphic subdivision of the whole Polish Basin (Fig. 3).

Newly defined lithoformations are based on the international principles of lithostratigraphical nomenclature (Hedberg *et al*., Eds., 1976; Alexandrowicz *et al*., In: Birkenmajer, Ed., 1975). The new lithostratigraphical division is by far clearer — number of units (formations) was reduced by three times (from 36 to 12). The units are defined in terms of lithofacies, boundaries and stratigraphy. The lithostratigraphic boundaries are clearly defined and less subjective — many of them are associated with sequence boundaries or transgressive surfaces, therefore lithofacies contrasts are easily identifiable. In the same time, the present author avoided introduction of new names of formations. All the lithoformations' names have already been in use for many years, so they are familiar to geologists. It was necessary to introduce two new subunits — Huta Mudstone Member (within Zagaje Formation) and Wola Korzeniowa Member (within Gielniów Formation). Definition of the superior unit (Kamienna Group) was also necessary. Another pursuit was to include natural exposures as hypostratotypes in characteristics of lithoformations. All localities of litho- stratotypes and hypostratotypes are shown on the Figs. 1 and 20.

KAMIENNA GROUP

All the defined herein formations (see the following text) can be arranged in the superior unit (group). The Early Jurassic epicontinental deposits of Poland represent siliciclastic deposits of varied continental, marginal-marine and marine origin and these deposits have their counterparts in the Danish, Swedish, German and Lithuanian basins. The dominant lithofacies (sandstones, heteroliths and mudstones) represent typical coal-bearing association and quartz sandstone association with subordinate shelf mudstone association.

Name: after the river Kamienna, which runs between Skarżysko Kamienna and Opatów across the area of natural and artificial exposures of the Early Jurassic deposits in the Holy Cross Mts region. Building stones, iron ores and clays of the Early Jurassic age have been exploited along the Kamienna river at least since the Early Medieval times.

Type area: exposures in the town of Starachowice (Pl. XIV, 2, 3) and other exposures along the Kamienna river and its tributaries (Gromadzice — Figs. 8, 11; Pl. XI, 7,8; Ostrowiec Świętokrzyski — Pl. XIV, 1; Opatów-Podole — Figs. 17, 18 CD; Pl. XII, 2, 3). Typical profiles: compound profile of the Early Jurassic deposits in Holy Cross Mts (Fig. 67), compiled from the following borehole profiles: Huta OP-1(Fig. 21 CD), Gliniany Las 2 (Fig. 4), Gliniany Las I (Fig. 5 CD), Mirzec MKR (Fig. 35 CD), Szydłowiec N-1 (Fig. 41 CD), Brody-Lubienia (Fig. 47 CD); Mechowo IG-1 profile (Fig. 31 CD) in the Pomerania region. Cores are stored in the archives of the Polish Geological Institute.

Thickness: maximum about 1400.0 m (central Poland, Mid-Polish Trough).

Dominant lithofacies: sandstones, heteroliths and mudstones.

Boundaries: lower — the erosional surface (= sequence boundary), truncating pre-Jurassic sediments; upper — contact with overlying Middle Jurassic deposits.

Age: Early Jurassic. In Pomerania it embraces also the Rhaetian deposits.

Distribution: the epicontinental basin of Poland. It is suggested, that the Kamienna Group can be also extended onto the adjacent areas (Southern Sweden, Bornholm, Lithuania).

Equivalents: Höganäs Formation and Rya Formation in Sweden; Fjerritslev Formation and Gassum Formation in the Danish Basin; Rønne Formation, Hasle Formation and Bagå Formation in Bornholm; Jotvingiai Group in Lithuania.

ZAGAJE FORMATION

Name: after the village of Zagaje near Gromadzice in the Holy Cross Mts region (Ostrowiec Świętokrzyski County, Świętokrzyskie Voivodship) — natural exposures of the formation occur around the village. The name introduced by Karaszewski (1960, 1962) as an informal lithostratigraphic unit.

Type locality: Miłków-Szewna borehole (depth 69.0–123.0 m, Fig. 19 CD), nearby the Zagaje village.

Hypostratotypes: Huta OP-1 borehole (depth 32.5–190.0 m, Fig. 21 CD), Szkucin exposures (Pl. XI, 1–3); Sołtyków exposure (Pls. XI, 4–6; XII, 1); the lower Gromadzice outcrop (Fig. 11; Pl. XI, 7, 8). Cores are stored in the archives of the Polish Geological Institute.

Thickness: maximum 157.5 metres (Huta OP-1 borehole).

Dominant lithofacies: poorly-sorted sandstones (wackes and quartz arenites) with trough cross-bedding sets; conglomerates are common in the lower part dominante in the upper part, mudstones with plant roots, plant fossils and coal seams. Origin — continental (alluvial and lacustrine depositional systems).

Boundaries: lower — is placed at the superregional erosional surface separating the underlying Upper Triassic red beds (containing calcareous nodules, hardpans, caliche horizons) from the overlying early Hettangian (in Pomerania also Rhaetian) grey sandstones and subordinately conglomerates; upper — a transgressive surface, representing contact between the underlying coal-bearing mudstones and the overlying heteroliths and sandstones of a nearshore (in places also lagoonal) origin.

Age: in the Holy Cross Mts — Earliest Hettangian (depositional sequence Ia, b); in the Wielkopolska region — Hettangian–Early Sinemurian (depositional sequence I–II); in Pomerania region — Middle–Late Rhaetian–Earliest Hettangian.

Distribution: Polish epicontinental basin except of the Mazury region and Częstochowa region.

Equivalents: The lower part of the Höganäs Formation in Scania (Southern Sweden) — Bjuv Member and the lowermost part of the Helsingborg Member (Boserup beds); Munkerup Member in Bornholm (Gravesen *et al*., 1982); Gassum Formation (Denmark) — Bertelsen, 1978. Abandoned names of informal units in Poland: lower Mechowo beds, Kłodawa series, lowermost Kalisz series, lower Połomia beds, lower Snochowice beds, Liwiec beds.

Zagaje Formation is built up mostly of sandstones (subordinately also conglomerates) of alluvial origin. However, its upper part in the Holy Cross Mts and in the central Poland shows dominance of the coal-bearing mudstones with plant roots and palaeosol levels (lacustrine depositional system). These strata (parasequence Ib) represent the "pre-transgression" succession associated with rising base level with clearly individualised lithology. Therefore, this sussession is distinguished and defined as the Huta Mudstone Member.

Huta Mudstone Member

Name: after the borehole located near the village of Huta (Fig. 20).

Type locality: Huta OP-1 borehole (depth 32.5–120.0 m, Fig. 21 CD), county Skarżysko-Kamienna.

Hypostratotype: Eugeniów-Korytków borehole (depth 56.1–95.0 m, Fig. 22 CD). The cores are stored in the archives of the Polish Geological Institute.

Thickness: maximum 87.5 metres.

Dominant lithofacies: dark-grey/olive-grey, laminated or massive mudstones and claystones (kaolinite-illite, sometimes containing swelling clay minerals), subordinate siltstones and fine-grained sandstones, abundant plant fossils, plant roots, palaeosol levels, siderite nodules and coal seams. Origin: lacustrine/backswamp depositional system.

Boundaries: lower — contact with the underlying coarser alluvial deposits; upper — a transgression surface — contact with overlying heteroliths or sandstones of brackish-marine origin.

Age: Early Hettangian, parasequence Ib.

Distribution: Holy Cross Mts region and probably the central Poland. Absent from the Wielkopolska region, Fore-Sudetic Monocline and central Pomerania (Mechowo IG 1).

Equivalents: lower Mechowo beds, the lowermost part of the Kalisz series, Liwiec beds (abandoned informal unit names).

SKŁOBY FORMATION

Name: after the village of Skłoby in the Holy Cross Mts region (Fig. 20). Introduced by Krajewski (1947) as an informal lithostratigraphic unit.

Type locality: Gliniany Las 2 (depth 11.0–51.0 m, Fig. 4) and Gliniany Las 1 (depth 50.0–90.0 m, Fig. 5 CD) — composed borehole profiles (in total, 90.0 m). Both boreholes (Fig. 20) are located in the Końskie County, Świętokrzyskie Voivodship.

Hypostratotypes: Miłków-Szewna borehole (depth 28.0–69.0 m, Fig. 19 CD); Eugeniów-Korytków borehole (depth 1.0–56.0 m, Fig. 22 CD); Pilichowice P-1 borehole (depth 27.0–50.0 m, Fig. 23 CD), Zawada PA-3 borehole (depth 3.0–89.0 m, Fig. 33 CD); Mechowo IG 1 borehole (depth 947.0–1105.0 m, Fig. 31 CD), Podole exposure (Fig. 17; Pl. XII, 2); the upper Gromadzice exposure (Fig. 8; Pls. XI, 7, 8; XII, 3); Wolica exposure (Pl. XII, 4); Starachowice exposure (Pl. XIV, 2, 3). Cores are stored in the archives of the Polish Geological Institute.

Thickness: maximum 160.0 m in the Pomerania region; 104.0 m in the Holy Cross Mts region.

Dominant lithofacies: well-sorted sandstones (quartz arenites) with hummocky cross stratification, horizontal bedding and cross bedding; heteroliths; abundant and diversified trace fossils. Origin — nearshore depositional system, deltaic and barrier/lagoon deposits prevail in the marginal parts of the basin.

Boundaries: lower — a transgressive contact with the underlying Zagaje Formation; upper (diachronous) — in most of the Polish Basin an erosional contact (sequence boundary) with the overlying alluvial sediments. In the Holy Cross Mts region — contact with the overlying siderite-bearing lagoonal mudstones (the lowermost "ore-bearing level") of the Przysucha Ore-bearing Formation.

Age: Middle Hettangian — depositional sequence I, parasequences Ic–f (Holy Cross Mts); Middle Hettangian–Late Hettangian — parasequences Ig–k (Pomerania region).

Distribution: the Mid-Polish Trough, Fore-Sudetic Monocline (Gorzów Wielkopolski IG 1 borehole). It is absent from the Wielkopolska region where it is replaced by the Zagaje Formation, from the Częstochowa region and the Baltic Syneclise.

Equivalents: middle part of the Helsingborg Member in Scania (cycles 5, 6, 7, 8 — Troedsson, 1951); Fjerritslev Formation (Danish Basin, central part) or Gassum Formation (Danish Basin, marginal parts — Bertelsen, 1978); lower Sose Bugt Member of the Rrnne Formation (Bornholm — Surlyk *et al*., 1995), Stanstorp Member — Höör Sandstone (Pieńkowski, 2002). Abandoned informal units in Poland: lower Mechowo beds, lower part of the Kalisz beds, Liwiec beds.

PRZYSUCHA ORE-BEARING FORMATION

Name: after the town of Przysucha, around which numerous outcrops and boreholes with deposits belonging to this formation occur. The name "Ore-bearing series" has been in traditional use since the early XIX-th Century (Push, 1833–1836); introduced as an informal lithostratigraphic unit by Kuźniar (1943).

Type locality: Gródek OP-2 borehole (depth 138.0–204.5 m, Fig. 38 CD) near Przysucha.

Hypostratotypes: Zapniów exposure (Pl. XII, 5), Podole OS-3 borehole (depth 27.0–57.0 m, Fig. 18 CD), Mirzec MKR borehole (depth 25.5–84.5 m, Fig. 35 CD), Głęboka Droga 2 borehole (depth 20.0–73.2 m, Fig. 37 CD). Cores are stored in the archives of the Polish Geological Institute.

Thickness: maximum about 80.0 metres.

Dominant lithofacies: mudstones and claystones with characteristic siderite bands; sandstones with various structures; heteroliths; plant fossils and plant roots common; trace fossils in places are common, dominated by fodinichnia. Origin — barier/lagoon and deltaic depositional system, in the basin's centre nearshore/embayment depositional systems.

Boundaries: lower — contact between the characteristic mudstones with sideritic bands (the so called "III-rd ore horizon") and the underlying pedogenic horizons (the uppermost part of Skłoby Formation); upper — erosional contact with overlying alluvial/deltaic sandstones.

Age: late Middle Hettangian–Late Hettangian; depositional sequence Ig–k.

Distribution: Holy Cross Mts region.

Equivalents: upper part of the Skłoby Formation in Pomerania (= middle part of the Mechowo beds), lower Kalisz series; upper Helsingborg Member (Scania, Southern Sweden); Gassum Formation, in basin's centre possibly also Fjerritslev Formation (Danish Basin), Sose Bugt Member (Bornholm).

Abandoned informal units in Poland: Ore-bearing series, Zarzecze series.

OSTROWIEC FORMATION

Name: after the town of Ostrowiec Świętokrzyski, around which exposures of the formation occur (Pl. XIV, 1). Introduced by Samsonowicz (1929) in the Holy Cross Mts region and described by Karaszewski (1960) as an informal lithostratigraphical unit.

Type locality: Szydłowiec N-1 borehole (depth 74.0–227.0 m, Fig. 41 CD, plus the lowermost 10 m of the formation based on the nearby Broniów-Krawara SP-4 borehole — Fig. 42).

Hypostratotypes: natural exposures near Ostrowiec Świętokrzyski (Pl. XIV, 1), Piekło exposures near Niekłań (Pl. XIV, 4, 6), quarries in Żarnów (Pl. XIV, 5), Pobiedziska IGH-1 borehole (depth 1463.5–1517.0 m, Fig. 63 CD), Gorzów Wielkopolski IG 1 borehole (depth 980.2–1096.5 m, Fig. 64 CD), Mechowo IG 1 borehole (depth 710.0–947.0 m, Fig. 31 CD). Cores are stored in the archives of the Polish Geological Institute.

Thickness: maximum about 240.0 metres

Dominant lithofacies: sandstones (most often quartz arenites) with hummocky cross bedding, other types of cross bedding and horizontal bedding; heteroliths; abundant and diversified trace fossils (in places *Diplocraterion parallelum* Torell); subordinate intervals of the profile are represented by coarser sandstones with abundant plant fossils and plant roots. Origin — nearshore depositional subsystem dominate, some intervals in Pomerania region represent marine lithofacies. At the base, in the middle and at the top of the formation three packages of alluvial/deltaic origin occur. At marginal parts of the basin, barrier-lagoon and deltaic depositional systems account for a substantial part of the formation.

Boundaries: lower — an erosional contact with the underlying Przysucha Ore-bearing Formation (Holy Cross Mts), Zagaje Formation (Wielkopolska region) or Skłoby Formation (in Pomerania region); upper — a transgressive contact with overlying marine/nearshore sediments of the Gielniów Formation or Łobez Formation.

Age: Sinemurian; depositional sequences II, III and the lowermost part of depositional sequence IV.

Distribution: Mid-Polish Trough, Fore-Sudetic Monocline; primary extend might have been wider.

Equivalents: Döshult Member, Pankarp Member, lowermost part of the Katslösa Member (Rya Formation) and Vittseröd Member (Pieńkowski, 2002) in Scania (southern Sweden); Fjerritslev Formation, at basin's margins Gassum Formation (Danish Basin); upper Sose Bugt Member and Galgeløkke Member (Bornholm). Abandoned informal units in Poland: upper Mechowo beds, Radowo beds, upper Ksawerów series, lower Main Sławęcin series, Kalisz series, Żarnów series, Koszorów series.

GIELNIÓW FORMATION

Name: after the town of Gielniów (Fig. 20), around which exposures of the formation occur. Introduced by Karaszewski (1960) in the Holy Cross Mts region as an informal lithostratigraphical unit.

Type locality: Jagodne 1 borehole (depth 14.0–87.0 m, Fig. 44 CD).

Hypostratotypes: Budki 1 borehole (depth 14.5–90.0 m, Fig. 43 CD); Szydłowiec N-1 borehole (depth 17.5–77.0 m, Fig. 41 CD); Pobiedziska IGH-1 borehole (depth 1398.5–1444.5 m, Fig. 63 CD); Gorzów Wielkopolski IG 1 borehole (depth 914.2–980.2 m, Fig. 64 CD); Rogów near Końskie exposure (Pl. XIII, 1); Bielowice exposure (Pl. XII, 7). Cores are stored in the archives of the Polish Geological Institute.

Thickness: maximum about 75 metres.

Dominant lithofacies: heteroliths, mudstones, horizontally-bedded fine-grained sandstones (quartz arenites), in places with chamosite, subordinately mudstones and sandstones with plant fossils. Trace fossils very abundant and diversified, *Diplocraterion parallelum* Torell is common. Marine bivalve fauna. Origin: marine — nearshore depositional systems (predominantly offshore-shoreface subsystems), subordinately barrier/lagoon depositional system and at the edges of the basin — deltaic depositional system.

Boundaries: lower — transgressive surface of the Early Pliensbachian marine deposits; upper — conspicuous erosional base of the sequence VI.

Age: Early Pliensbachian; depositional sequences IV and V.

Distribution: Holy Cross Mts region, Wielkopolska region, Fore-Sudetic Monocline.

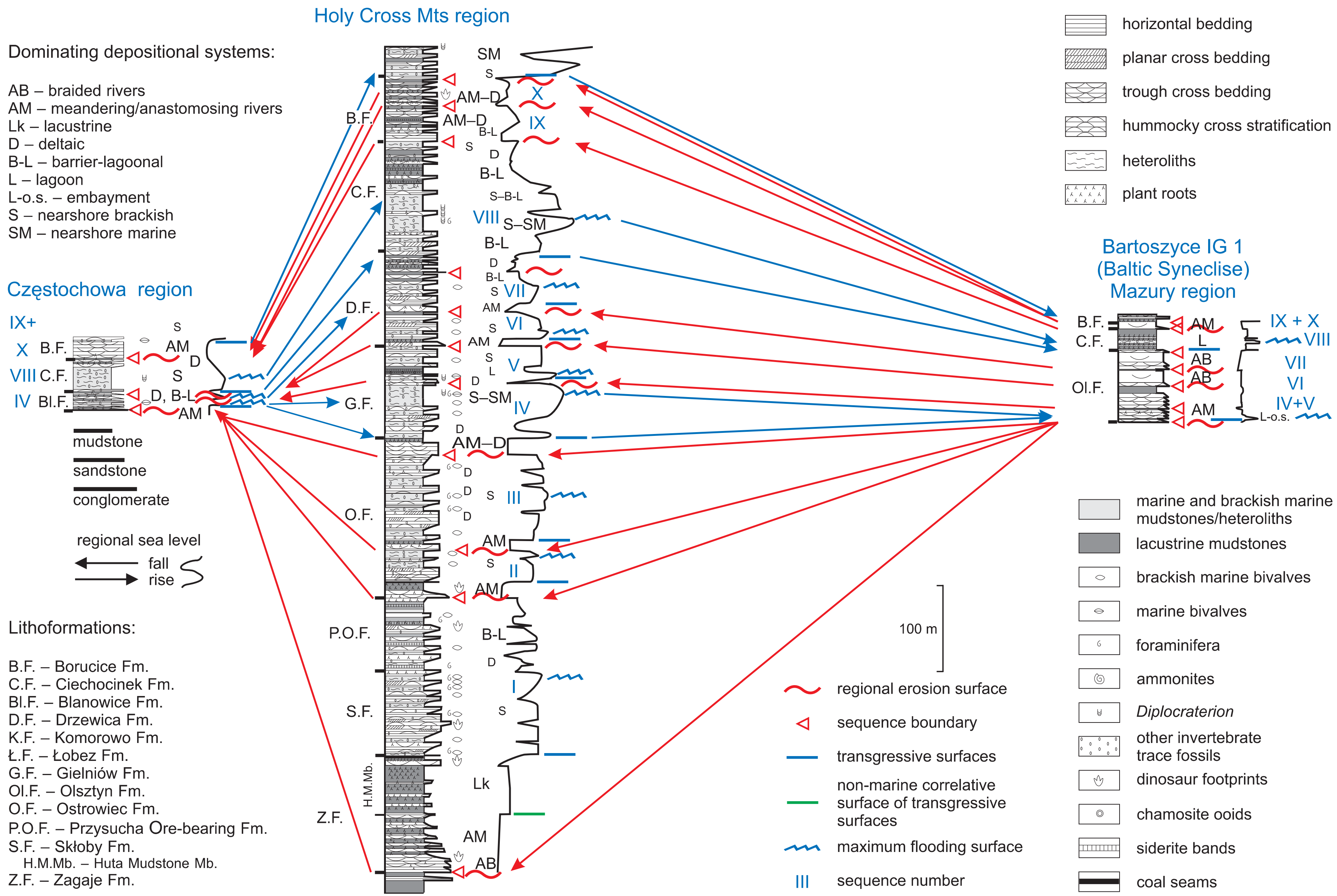


Fig. 67. Section of the Early Jurassic deposits in the Polish Basin (see Fig. 1), running across the basin from the Częstochowa region, through the Holy Cross Mts region to the Mazury region

Note substantial increase of sediment thickness in the Mid-Polish Trough (Holy Cross Mts region). Hettangian–Sinemurian depositional sequences and lithoformations wedge out both in the SW and NE directions

Equivalents: Łobez Formation (Pomerania region), lower part of Blanowice Formation (Częstochowa region), lower part of Olsztyn Formation (Baltic Syneclise), Katslösa Member of the Rya Formation (Southern Sweden), Fjerritslev Formation (Danish Basin), Hasle Formation (Bornholm), lower Neringa Formation (Lithuania).

Wola Korzeniowa Member

Name: after the Wola Korzeniowa village south of Szydłowiec. The stratotype borehole Szydłowiec N-1 is actually situated at the road from Szydłowiec to Wola Korzeniowa (Fig. 20).

Type locality: borehole Szydłowiec N-1 (depth 46.0–67.5 m, Fig. 41 CD). Core stored in the archives of the Polish Geological Institute.

Thickness: maximum about 22.0 metres.

Dominant lithofacies: grey, medium- and fine-grained, trough cross bedded sandstones with abundant plant fossils. Mud clasts are frequent. Origin: deltaic depositional system (distributary channel subsystem).

Boundaries: lower — contact with the underlying marine/brackish marine deposits of parasequence IVb; upper — a transgressive contact with the overlying shoreface sandstones of parasequence IVc (Fig. 41 CD).

Age: Early Pliensbachian; a part of parasequence IVb.

Distribution: northern edge of the Holy Cross Mts region. Wola Korzeniowa Member forms an isolated, some 12 km-wide and 20–25 m thick lenticular lithosome of deltaic deposits within nearshore-marine deposits of the Gielniów Formation (Fig. 46). Development of the Wola Korzeniowa Member was associated with rejuvenation of the Nowe Miasto–Iłża fault zone (Fig. 20).

Equivalents: it is a time equivalent of the parasequence IVb (Early Pliensbachian).

ŁOBEZ FORMATION

Name: after town of Łobez in Pomerania, name introduced as an informal lithostratigraphic unit by Dadlez (1964a).

Type locality: Mechowo IG 1 borehole (depth 573.0–710.0 m, Fig. 31 CD).

Hypostratotype: Kamień Pomorski IG 1 borehole (depth 135.0–291.0 m, Fig. 32 CD). Cores are stored in the archives of the Polish Geological Institute.

Thickness: maximum about 160.0 metres.

Dominant lithofacies: dark-grey mudstones with dispersed pyrite concretions and lenticular heteroliths. Trace fossils are represented by *Chondrites*, *Palaeophycus* and Helminthoida. Marine fauna, including ammonites. Origin — open marine shelf, subordinate parts represent nearshore depositional system or embayment depositional subsystem.

Boundaries: lower — a transgressive surface of the Early Pliensbachian marine deposits; upper — conspicuous erosional surface at the base of sequence VI.

Age: Early Pliensbachian, parasequence IV and lower part of parasequence V.

Distribution: Pomerania region.

Equivalents: Gielniów Formation, the lower part of Blanowice Formation (Częstochowa region), the lower part of Olsztyn Formation (Baltic Syneclise), Katslösa Member of the Rya Formation (Southern Sweden), Fjerritslev Formation (Danish Basin), Hasle Formation (Bornholm), lower Neringa Formation (Lithuania).

DRZEWICA FORMATION

Name: after the town of Drzewica (Holy Cross Mts region; Fig. 20), name introduced by Karaszewski (1962) as an informal lithostratigraphical unit.

Type locality: Brody-Lubienia borehole (depth 181.2–270.0 m, Fig. 47 CD).

Hypostratotypes: Zychorzyn borehole, (Fig. 45 CD, depth 0.0–96.0 m); Skrzynno exposure (Pl. XII, 8); Szydłowiec exposure (Pl. XIII, 2), Śmiłów near Szydłowiec exposure (Pl. XIII, 3–7), Pobiedziska IGH-1 borehole (depth about 1310.0–1398.5 m, Fig. 63 CD). Cores are stored in the archives of the Polish Geological Institute.

Thickness: maximum about 100.0 metres.

Dominant lithofacies: sandstones with all types of cross bedding, subordinately heteroliths and mudstones. Diversified trace fossils are common. Plant fossils are common. Origin — nearshore depositional system, delta depositional system, barrier-lagoon depositional system.

Boundaries: lower — erosional contact with the underlying marine sediments of the Gielniów Formation; upper — transgressive contact with the overlying greenish-grey mudstones of Ciechocinek Formation.

Age: Late Pliensbachian; in the Holy Cross Mts region — latest Early Pliensbachian–Late Pliensbachian; parasequences VI, VII and lowermost part of parasequence VIII, in Pomerania region also the upper part of the parasequence V.

Distribution: Holy Cross Mountains region, central Poland.

Equivalents: Komorowo Formation (Pomerania region), the upper part of Blanowice Formation (Częstochowa region), Rydeback Member of the Rya Formation (Southern Sweden), Fjerritslev or Gassum Formation (Danish Basin), lower Bagå Formation (Bornholm), upper Neringa Formation (Lithuania). Abandoned informal units in Poland: upper Sławęcin beds, Wieluń series, Bronów series.

KOMOROWO FORMATION

Name: after small town of Komorowo in Pomerania region. Name introduced by Dadlez (1964a) as an informal lithostratigraphical unit.

Type locality: Mechowo IG 1 borehole (depth 408.5–573.0 m, Fig. 31 CD).

Hypostratotypes: Kamień Pomorski IG 1 borehole (42.0–135.0 m, Fig. 32 CD), Gorzów Wielkopolski IG 1 borehole (depth 848.2–914.0 m, Fig. 64 CD). Cores are stored in the archives of the Polish Geological Institute.

Thickness: maximum about 165.0 metres.

Dominant lithofacies: sandstones with all types of cross bedding, subordinately heteroliths and mudstones. Heterotiths are more frequent in the western part of the Pomerania region and in the upper part of the Komorowo Formation, where abundant and diversified trace fossils and fauna with ammonites occur. Origin: in the lower part predominantly alluvial/deltaic depositional system, in the upper part — a nearshore depositional system and an open marine shelf depositional system.

Boundaries: lower — erosional (the base of sequence VI), very conspicuous contact with the underlying marine sediments of the Łobez Formation. Alluvial (?deltaic) sandstone deposits are extended far basinward — they occur in Wolin IG 1 borehole (depth 1001.5 m–1011.0 m) in westernmost Pomerania (Dadlez, 1975). In Pomerania region, the sequence boundary and overlying coarse alluvial/deltaic clastics separate the marine deposits of Łobez Formation from the upper, marine part of the Komorowo Formation. (thus, even in the westernmost Pomerania the upper Komorowo Formation does not merge with the Łobez Formation). Upper boundary — a transgressive contact with the overlying greenish-grey mudstones of Ciechocinek Formation.

Age: Late Pliensbachian; depositional sequences VI, VII and the lowermost part of depositional sequence VIII.

Distribution: Pomerania region, western part of the Fore-Sudetic Monocline.

Equivalents: Drzewica Formation (Holy Cross Mts and central Poland), upper part of the Blanowice Formation (Częstochowa region), Rydeback Member of the Rya Formation (Southern Sweden), Fjerritslev or Gassum Formation (Danish Basin), lower Bagå Formation (Bornholm), upper Neringa Formation (Lithuania). Abandoned informal units in Poland: upper Sławęcin beds, Wieluń series, Bronów series.

BLANOWICE FORMATION

Name: after the Blanowice suburb of Zawiercie (Figs. 1, 49), where the Early Jurassic coal seams were exploited; name introduced by Znosko (1955) as an informal lithostratigraphical unit, stratigraphically reinterpreted by Dadlez (1969) and Deczkowski, Daniec (1981).

Type locality: Parkoszowice 58 BN borehole (depth 159.0–172.2 m, Fig. 60 CD).

Hypostratotypes: Jaworznik 132 Ż borehole (136.3–152.0 m, Fig. 58 CD); Wręczyca 3/81 borehole (depth 124.0–146.5 m, Fig. 54 CD); Bolesławiec 6 borehole (depth 44.5–60.0 m, Fig. 51 CD). Cores are stored in the archives of the Polish Geological Institute.

Thickness: maximum about 42.0 metres (Przystajń 2/81, depth 108.2–149.8 m, Fig. 53 CD).

Dominant lithofacies: sandstones with different cross bedding sets and horizontal bedding, subordinately mudstones, heteroliths, coal seams. Plant fossils and plant roots are abundant, only in some places (Włodowice52 BN, Fig. 59 CD) plant fossils are rare and trace fossils are numerous. Origin: predominately deltaic-distributary/alluvial/lacustrine, locally marginal marine (nearshore, barrier-lagoon/embayment depositional systems).

Boundaries: lower — the erosional sequence boundary with large hiatus (at least Rhaetian, Hettangian, and Sinemurian deposits are lacking); upper — a transgressive surface, overlain by the greenish-grey mudstones of Ciechocinek Formation.

Age: Pliensbachian; depositional sequences IV, V, VI, VII and in places lowermost part of depositional sequence VIII.

Distribution: Częstochowa region (Fig. 49).

Equivalents: Gielniów Formation and Drzewica Formation (Holy Cross Mts and central Poland), Łobez Formation and Komorowo Formation (Pomerania region), Olsztyn Formation (Baltic Syneclise), Rydeback Member of the Rya Formation (Southern Sweden), Fjerritslev or Gassum Formation (Danish Basin), Bagå Formation (Bornholm), Neringa Formation (Lithuania). Abandoned Polish equivalents: upper Sławęcin beds, Wieluń series, Bronów series.

OLSZTYN FORMATION

Name: after town of Olsztyn, name introduced by Dadlez (1968) as an informal lithostratigraphical unit.

Type locality: Bartoszyce IG 1 borehole (depth 735.5–821.0 m, Fig. 66 CD); core is stored in the archives of the Polish Geological Institute.

Thickness: according to Dadlez (1968), maximum about 180.0 metres.

Dominant lithofacies: medium- to coarse-grained, trough cross bedded sandstones, subordinate fine-grained sandstones, mudstones are very rare. Origin: alluvial (braided and/or meandering channel depositional systems), in the lower part – embayment/nearshore/deltaic depositional system.

Boundaries: lower — the erosional sequence boundary truncating the Upper Triassic deposits (large hiatus); upper — transgressive contact with the nearshore sandstones and greenish-grey mudstones of Ciechocinek Formation.

Age: Pliensbachian; depositional sequences IV, V, VI, VII and the lowermost part of depositional sequence VIII.

Distribution: Baltic Syneclise (Mazury region, Kaliningrad region, Lithuania).

Equivalents: Gielniów Formation and Drzewica Formation (Holy Cross Mts and central Poland), Łobez Formation and Komorowo Formation (Pomerania region), Rydeback Member of the Rya Formation (Southern Sweden), Fjerritslev or Gassum Formation (Danish Basin), Bagå Formation (Bornholm), Neringa Formation (Lithuania). Abandoned informal units in Poland: upper Sławęcin beds, Wieluń series, Bronów series.

CIECHOCINEK FORMATION

Name: after the town of Ciechocinek in central Poland. Name introduced by Różycki (1958) as an informal lithostratigraphical unit, based on description of then existing cores.

Type locality: as no sufficient core material is available from the Ciechocinek area (a former type locality region), in order to retain the long-used name, a neolithostratotype is established in the Mechowo IG 1 borehole (depth 291.2–408.5 m, Fig. 31 CD). The Ciechocinek Formation is widely distributed all over the Polish Basin.

Hypostratotypes: Brody-Lubienia borehole (depth 101.5–181.5 m, Holy Cross Mts region, Fig. 47 CD); Gorzów Wielkopolski IG 1 borehole (depth 767.2–848.2 m, Fore-Sudetic Monocline, Fig. 64 CD); Nowa Wieś 12 borehole (depth 26,2 – 92 m, Częstochowa region, Fig. 52 CD); Kozłowiec outcrop (Częstochowa region, Pl. XIII, 8); Bartoszyce IG 1 borehole (depth 710.5–735.5 m, Baltic Syneclise, Fig. 66 CD). Cores are stored in the archives of the Polish Geological Institute.

Thickness: maximum 140.0 metres (central Poland — Dadlez, 1978).

Dominant lithofacies: greenish-grey, locally grey heterotiths (predominantly lenticular bedding occur), mudstones, in places claystones; intercalations of siltstones and fine-grained sandstones with all types of cross-bedding. Horizons with abundant plant fossils and plant roots are common, but intervals with numerous trace fossils (including *Diplocraterion parallelum* Torell) also occur. Characteristic green colour (“verdine facies”) comes from chlorite content. Origin: a large, shallow, brackish marine embayment; in the marginal parts delta facies occur. Some parts in Pomerania represent somewhat deeper, nearly fully-marine basin.

Boundaries: lower — a transgressive surface overlying the underlying alluvial/deltaic sandstones of the uppermost Drzewica or Komorów Formation; upper — erosional surface with overlying coarse deposits of the lowermost Borucice Formation (sequence IX lower boundary).

Age: Early Toarcian; depositional sequence VIII.

Distribution: Early Jurassic epicontinental basin in Poland (the widest distribution of all the Early Jurassic formations).

Equivalents: Posidonia Shale (Germany), upper part of the Rydeback Member, Rya Formation (Southern Sweden), Fjerritslev Formation (Danish Basin), Bagå Formation (Bornholm), Lava Formation (Lithuania). Abandoned informal units in Poland: Gryfice beds (Pomerania region), lower Łysiec beds (Częstochowa region), “Estheria series”.

BORUCICE FORMATION

Name: after the village of Borucice in the Kujawy area, central Poland (Fig. 1). Name introduced by Różycki (1958) as an informal lithostratigraphical unit, based on description of then existing cores (Fig. 3).

Type locality: as no sufficient core material is available from the Kujawy area (a former type locality region), in order to retain the long-used name, a neolithostratotype is established in the Brody-Lubienia borehole (depth 6.7–101.5 m; Holy Cross Mts region, Fig. 47 CD). The Borucice Formation is widely distributed in the Polish Basin.

Hypostratotypes: Mechowo IG 1 borehole (depth 228.0–291.2 m, Pomerania region, Fig. 31 CD). Gorzów Wielkopolski IG 1 borehole (depth 756.5–767.2 m; Fore-Sudetic Monocline, Fig. 64 CD), Suliszowice 38 BN borehole (depth 290.8–313.5 m; Częstochowa region, Fig. 56 CD); Bartoszyce IG-1 borehole (depth 702.0–710.5 m; Baltic Syneclise, Fig. 66 CD). Cores are stored in the archives of the Polish Geological Institute.

Thickness: maximum about 120.0 metres (central Poland — Dadlez, 1978).

Dominant lithofacies: medium- to coarse-grained, trough cross bedded sandstones, subordinate fine-grained sandstones; mudstones are rare. Plant fossils and plant roots are common. Origin: alluvial (braided or meandering channel) depositional systems; subordinate intervals of deltaic deposits occur only in the Mid-Polish Trough.

Boundaries: lower — erosional sequence boundary with Ciechocinek Formation; upper — transgressive contact with overlying nearshore sandstones of the Middle Jurassic age (Kościelisko beds).

Age: Late Toarcian; depositional sequences IX and X, it may comprise lowermost parts of the first Middle Jurassic sequence.

Distribution: epicontinental basin in Poland.

Equivalents: upper Rya Formation (Southern Sweden), Bagå Formation (Bornholm). Abandoned informal units in Poland: Kamień beds (Pomerania region), upper Łysiec beds (Częstochowa region).

SEQUENCE STRATIGRAPHY OF THE EARLY JURASSIC EPICONTINENTAL DEPOSITS IN POLAND IN COMPARISON TO THE WEST EUROPEAN STANDARDS

Depositional system development and arrangement of depositional sequences has been presented in form of cross sections (both across the basin and parallel to its axis) — Figs. 67–70 and palaeogeographical maps — Fig. 71. Major cross-sections were constructed along the following lines (Fig.1): from the region of Częstochowa, through the Holy Cross Mts region, to the Baltic Syneclise (Bartoszyce IG 1) — Fig. 67; from the Wielkopolska region (Pobiedziska IGH 1), through the Fore-Sudetic Monocline (Gorzów Wielkopolski IG 1) to the Pomerania region (Chabowo IG 2 and Mechowo IG 1) — Fig. 68; and from the Częstochowa region, through the Holy Cross Mts region to the Pomerania region. The sections show the lateral extent of depositional sequences and their major bounding surfaces: sequence boundaries, transgressive surfaces (and correlative surfaces) and maximum flooding surfaces, against a background of general lithofacies and depositional systems (Figs. 69, 70).

Poland-wide comparison of sequence boundaries shows that the erosional boundaries of depositional sequences: I, II, VI and IX are particularly conspicuous and, additionally, lower boundaries of sequences I and VI are characterised by deepest erosion. Therefore initial sedimentation of coarse alluvial sediments of those sequences is characterised by very wide lateral extent (in case of the sequences I and VI possibly down to shelf margins), producing particularly conspicuous superregional bounding surfaces. Within the continental deposits at the basin margins (usually beyond the Mid-Polish Trough), the lower boundaries of depositional sequences: I, II, VI and IX, are associated with intense erosion, which could remove part (or whole) of the previously deposited sediments in the marginal parts of the basin (Figs. 70, 71). It is believed that erosion at sequence boundaries were coeval with development elsewhere of the lowstand (LST) and falling stage systems tract (FSST).

In contrast, maximum flooding surfaces corresponded with phases of maximum expansion of the basin and basinal facies onto marginal-marine and continental areas.

Thus, sequence boundaries play particularly important correlative role in basinal facies, while maximum flooding surfaces are of particular correlative significance in continental areas. Stratigraphic significance of the transgressive surfaces is enhanced if they are coupled with their continental correlatives (Figs. 24–26, 61, 68, 69).

Finally, regional cross sections can be correlated with superregional sea level changes — the Exxon curve (Haq *et al*., 1987) and the regional sea level curve presented by Hesselbo and Jenkyns (1998) — Figs. 69, 70, 72, adjusted to the time scale of Gradstein *et al*. (1995). Moreover, some striking similarities occur between inferred sea level fluctuations in the Polish Basin and the sequence order from France (de Graciansky *et al*., 1998b) and Denmark (Nielsen, 2003) Sedimentation was influenced by number of factors, such as local subsidence and compaction, tectonic movements (for example active in Pliensbachian times in Pomerania as well as along the Nowe Miasto–Iłża Fault zone in the Holy Cross Mts region), associated with displacement of rock salt masses and sediment supply. Nevertheless, the Early Jurassic sedimentation in the Polish epicontinental basin was chiefly controlled by superregional sea level changes, which left its super-regional imprint comparable with mentioned curves (Figs. 69–72). As far as concerns number and range of sequences, the Exxon curve (Haq *et al*., 1987) seems to present better framework when compared to the Polish material. All ten of Exxon's depositional sequences were distinguished in the Polish Lower Jurassic, although the two uppermost ones from Poland (IXth and Xth — Late Toarcian) are often amalgamated and difficult to differentiate. On the other hand, regional sea level changes presented by Hesselbo and Jenkyns (1998) and de Graciansky *et al.*. (1998b) — Figs. 69, 72, give more precise dating of certain events and much more detailed record of sea level changes, which even allow correlation of some parasequences distinguished in the Polish Basin.

It should be pointed out that the term "superregional sea level changes" used in this paper means changes of sea level registered and dated in North European basins, chiefly the North Sea, onshore United Kingdom and France (Ligurian Cycle — de Graciansky *et al*., 1998a). Most of these changes are believed to be of global (eustatic) character (Duval *et al*., 1998), although concept of coeval world-wide sea level changes is a matter of controversy (Cloetingh *et al*., 1985; Ziegler, 1988; Cathles, Hallam, 1991). One should bear in mind that rift development, including the rate of crustal extension and the rate of subsidence, differed from one structural province to the other (Ziegler, 1988). This, however, does not impact greatly on the correlations between the North–Central European basins (Ligurian Cycle — Jacquin, de Graciansky, 1998; de Graciansky *et al*., 1998a), which show fairly uniform development of transgressive-regressive phases, and, consequently, should not greatly affect the Polish Basin, situated on the same plate.

Comparison of transgressive/regressive facies cycles and depositional sequences for the Early Jurassic Epoch in Western Europe show that ages of peak transgressions and main cycle boundaries can vary regionally according to the local extensional tectonic development (de Graciansky *et al*., 1998a). However, most of the twenty seven 3rd-order depositional sequences comprising the Ligurian major cycle can be documented from the North Sea to Southern Europe. Sea level changes (both 3rd and 2nd order) in the Northern areas of Europe (Boreal province) were taken as the basic "pattern" for the sea level comparison in the present work (Fig. 72).

DEPOSITIONAL SEQUENCE I (HETTANGIAN)

The earliest Jurassic (Hettangian) was a time of widespread igneous activity and thick accumulation of strata in the rift basins of the Atlantic margins. The observed changes around the Triassic/Jurassic boundary and the coeval extensional events associated with reorganisation of the subsidence pattern, onset of platform breakup and volcanism are surprisingly synchronous with Tethyan or Atlantic events (Dumont, 1998). This was a likely mechanism of the sea level changes (de Graciansky *et al*, 1998b). The earliest Hettangian is also associated with major turnover in evolution: at the end of the Triassic, the Ceratitida went extinct and were replaced in the Early Hettangian by first Ammonitida, which was associated with a regressive latest Triassic phase followed by the Hettangian transgression (Hallam, 1997; Sandoval *et al*., 2001).

Thanks to the most complete exposure and core recovery, recognition of the depositional sequence I is best of all the Early Jurassic depositional sequences in Poland. The sequence boundary coincidences with the Triassic–Jurassic boundary. The Triassic-Jurassic boundary involves successive shallowing, with widespread emergence and erosion (Hallam, 1997; Niel-

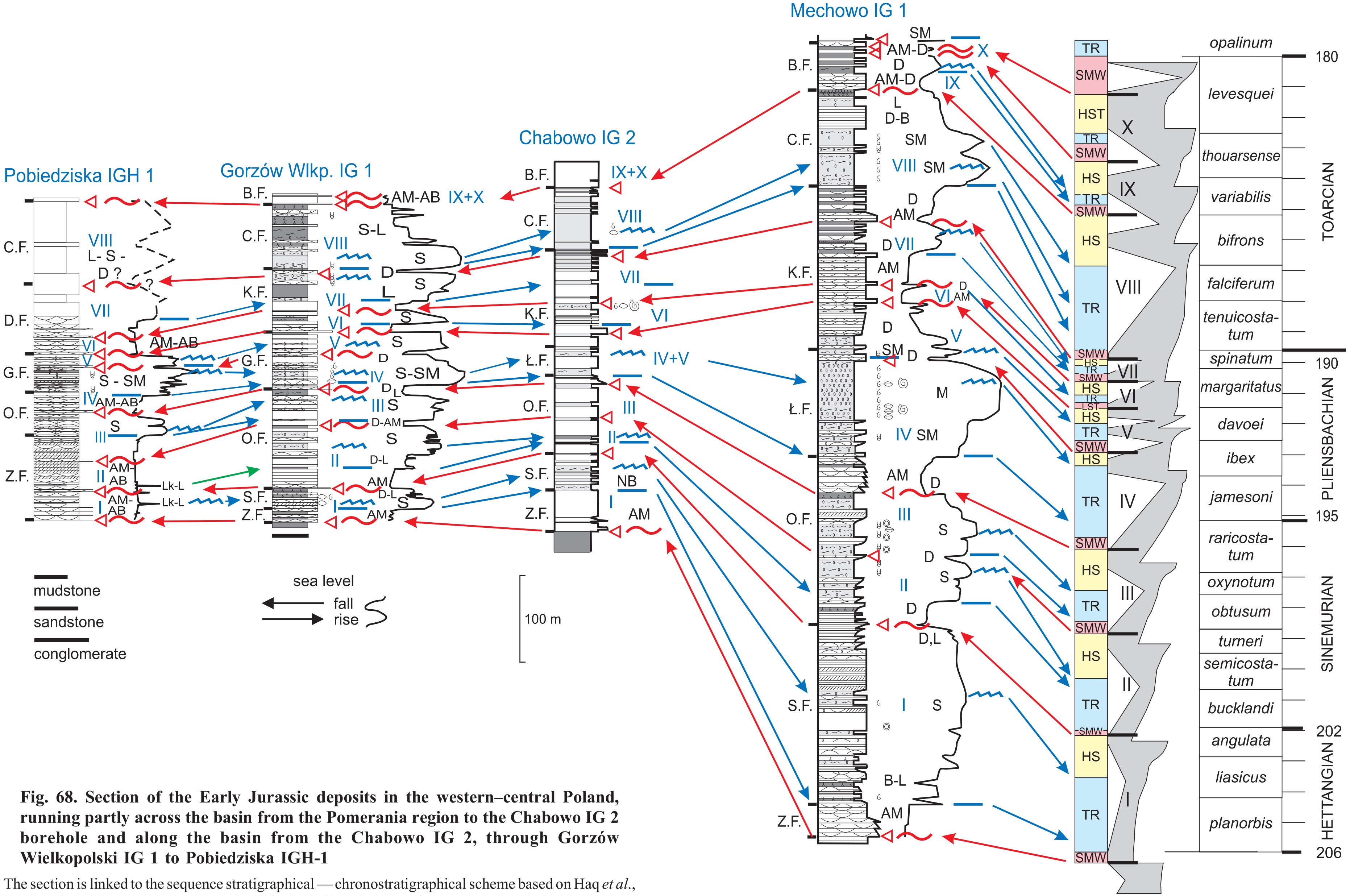


Fig. 68. Section of the Early Jurassic deposits in the western–central Poland, running partly across the basin from the Pomerania region to the Chabowo IG 2 borehole and along the basin from the Chabowo IG 2, through Gorzów Wielkopolski IG 1 to Pobiedziska IGH-1

The section is linked to the sequence stratigraphical — chronostratigraphical scheme based on Haq *et al.*, 1987 and Gradstein *et al.*, 1995. Simplified profile of the Chabowo IG 2 borehole is based on Feldman-Olszewska (1988). For explanation see Fig. 67; for localities see Fig. 1

sen, 2003)), which is exactly the case in the Polish Basin. When Rhaetian sediments are missing, this boundary is merged with even more significant sequence boundary of the Late Norian (Early Cimmerian unconformity — Jacquin, de Graciansky, 1998).

Depositional sequence I in Poland commences with package of "pre-transgression" package of alluvial sediments, which are thicker in the Holy Cross Mts region and thinner in the Pomerania region (Figs. 24 A, B; 26; 69; 71: 1). Ensuing sedimentation marks the beginning of the transgressive systems tract and correspond with the world-wide (? truly eustatic — Hallam, 1997) sea level rise of the earliest Jurassic age (Early Hettangian, *planorbis* Zone, *psilonotum* Subzone), which immediately followed the latest Rhaetian shallowing event (Haq *et al*., 1987; Bloos, 1990; Hallam, 1997). Sea level rise of the *planorbis* Zone is confirmed by many authors (Donovan *et al*., 1979; Haq *et al*, 1987; Bloos, 1990; de Graciansky *et al*, 1998b; Dumont, 1998). In Poland, sea level rise led firstly to the initial sedimentation of alluvial deposits (pre-transgression package, parasequence Ia: Figs. 24 A, B; 25, 70, 71: 1). The lowermost parasequence Ia is generally restricted to the Mid Polish Trough or its nearby edges (Figs. 70, 71: 1), as evidenced by its spatial range in the Holy Cross Mts section of the Mid-Polish Trough (Fig. 25). Possibly, this lowermost parasequence is in part an equivalent of the "pre-*planorbis*" beds (Dumont, 1998).

Further sea level rise occurred in the *planorbis* Zone and led to the rapid expansion of the basin beyond the Mid-Polish Trough, associated with replacement of coarse alluvial sediments by fine lacustrine sediments — also in the marginal parts of the basin (Figs. 24, 25, 70, 71: 2). This lithofacies shift corresponds with the parasequence Ia/Ib boundary, which is likely coeval with the transgressive surface in the Pomerania region (Figs. 26, 69) and in Germany — immediately above the fluviatile, "channelised" Hettangian deposits (Bloos, 1976, 1984, 1990). Thus, the lacustrine deposits in the Holy Cross Mts region (Huta Mudstone Member) are coeval with the nearshore/barrier-lagoon deposits in the Pomerania region (lowermost part of the Skłoby Formation), and both represent parasequence Ib.

Progradational trends are visible in the uppermost part of the parasequence Ib in the fringe areas of the Holy Cross Mts region (re-appearance of the alluvial deposits — Figs. 11, 25; Figs. CD: 19, depth 70.0–90.0 m; 23, depth 50.8–54.0 m), as well as in the Fore-Sudetic Monocline (Fig. 64 CD, depth 1120.0–1122.0 m) and in Pomerania region (lagoonal-marsh deposits — Fig. 31 CD, depth 1096.0–1098.0 m). This may indicate a decrease in pace of the sea level rise, as the progradation occurred in the whole basin.

In that context, it is noteworthy that the Hettangian section in France is actually divided into two sequences: He_1 and He_2 (de Graciansky *et al*., 1998b), the next He_3 sequence comprise both uppermost Hettangian and lowermost Sinemurian. The He_1 and He_2 sequences are separated by a regression, culminating at a sequence boundary dated to the latest *planorbis* Zone (latest *johnstoni* Subzone — transition with *portlocki* Subzone). Hesselbo and Jenkyns (1998) also reported regression trend in latest *planorbis* Zone (latest *johnstoni* Subzone), although their interpretation of the Hettangian section was tentative. The same regression/progradation is noted by Dumont (1998) from the Western Alps. The question remains about the rank of mentioned sea level fluctuations — if they are of a sequence or rather parasequence scale. Nevertheless, the progradation of lithofacies observed in the uppermost part of the parasequence Ib in Poland may well corresponds to the similar trends in the Lower Jurassic of United Kingdom and France, thus it would be likely dated to the *johnstoni/portlocki* subzone transition.

Brackish marine transgression reached the Holy Cross Mts region slightly later, at the base of the next parasequence Ic. From that time on, sedimentation in the Holy Cross Mts, Pomerania region and Fore-Sudetic Monocline became unified (with domination of nearshore deposition). The remaining part of the transgressive systems tract is represented by a retrogra- dational set of parasequences Ic–f (Figs. 48: 1, 2; 71: 3). The maximum flooding surface occurred in the parasequence If (Figs. 48: 2; 71: 3). Deposits of parasequences Ic, Id, Ie and particularly that of the parasequence If extend far beyond the Mid-Polish Trough. However, beyond the Mid-Polish Trough they are much thinner and may be represented either by nearshore-marginal marine (Fore-Sudetic Monocline, Fig. 64 CD), or continental depositional systems (Figs. 63 CD; 71: 3. This expansion is particularly visible in the Wielkopolska region (Pobiedziska IGH 1, depth 1554.0–1585.0 m, Fig. 63 CD), where depositional sequence I is developed for the most part as coarse alluvial sediments. The thin mudstone intercalation of lagoonal origin marks expansion phase of the basin associated with the maximum flooding surface (depth 1586.0–1587.0 m). This part of transgressive systems tract in Poland would correspond to the *liasicus* Zone (*portlocki*–lower *laqueus* subzones). The maximum flooding surface would be dated to the late *liasicus* Zone (lower *laqueus* Subzone), which is associated with maximum flooding surface in Europe (Haq *et al*., 1987; Hallam, 1988, 1997; Hesselbo, Jenkyns, 1998; de Graciansky *et al*, 1998b).

The occurrence of pronounced marine influences in the parasequence If (marine palynofacies with dinoflagellate cysts) in the southern part of the Holy Cross Mts region (Fig. 5 CD, Gliniany Las 1, depth 70.0–80.0 m; Pl. VI, 4; Pawłowska, 1962) should be addressed. The Hettangian marine influences in the Holy Cross Mts region are at least equal to those in Pomerania region, where marine influences are expected to be stronger. It may suggest that the Early Jurassic basin in the Mid-Polish Trough was episodically connected with the Tethys Basin (an unknown "southern way"). Moreover, the relatively pronounced marine influences in the Pliensbachian and Early Toarcian deposits in Częstochowa region (Figs. 61, 62; 71: 8, 11) could also suggest proximity of a connection with the open sea. This connection was already postulated by Karaszewski and Kopik (1970) and as the Fore-Carpathian Land was rather narrow (Fig. 1), this would be theoretically possible (Fig. 71: 3). Some episodic connections with the Tethys Basin could occur particularly during the periods of highest sea level (Fig. 71: 6, 8, 11). These connections could provide ways for migrations of marine organisms, thus explaining their presence in the southernmost section of the Mid-Polish Trough and even further migration to the Pomerania region and East German area. Moreover, short-lived existence of such connections could enhance faunal or

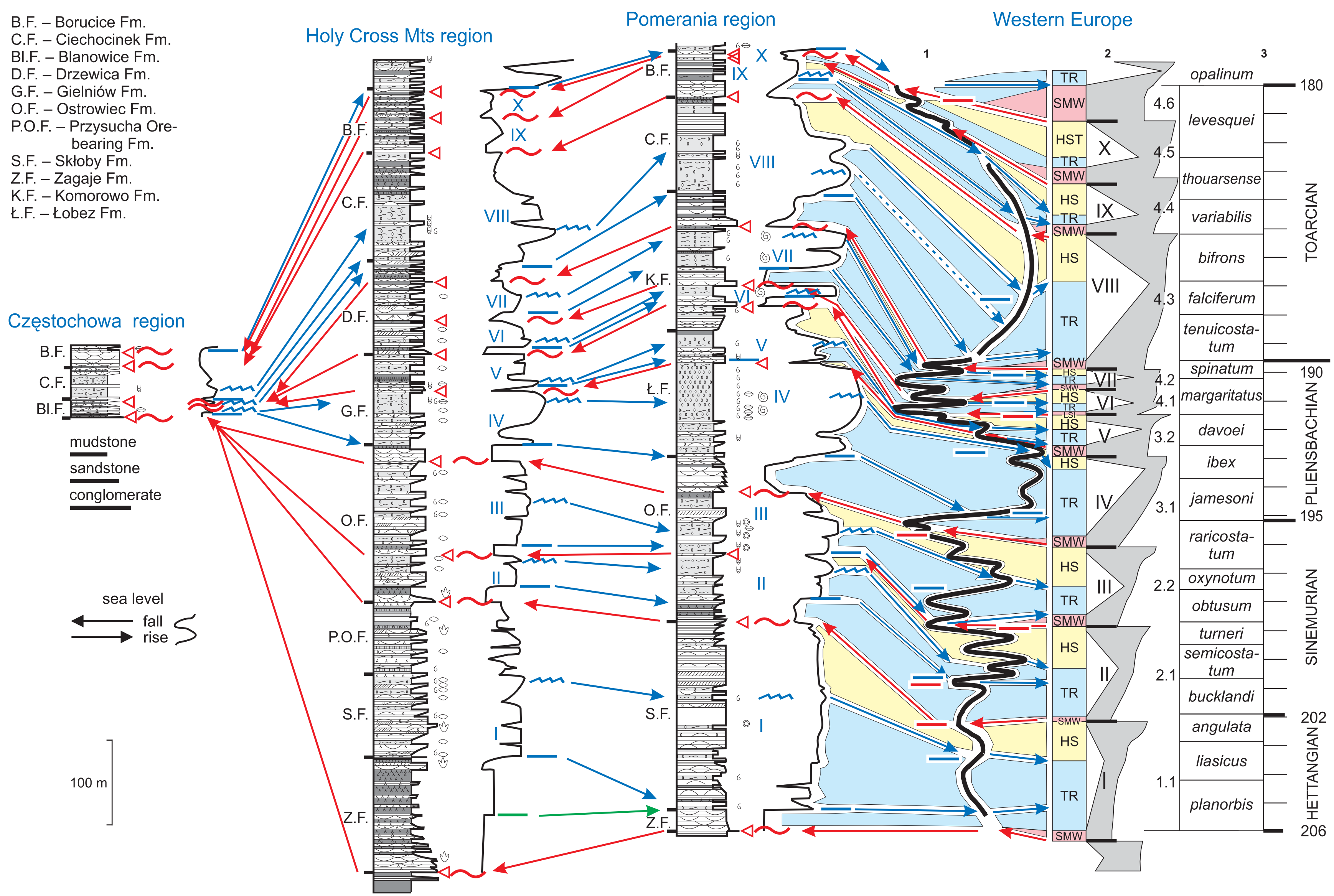


Fig. 69. Overall section of the Early Jurassic deposits in the Polish Basin running across the basin from the Częstochowa region to the Holy Cross Mts region, and then along the basin (Mid-Polish Trough) to the Pomerania region

The section is correlated with the sequence stratigraphic interpretation and relative sea level chart of 1 — the Lower Jurassic of the British area based on Hesselbo, Jenkyns, 1998 (red bars — their major candidate sequence boundaries, blue bars — their major candidate maximum flooding surfaces); 2 — the world-wide sequence stratigraphic scheme based on Haq *et al.*, 1987, with respective numbers of the Upper Absaroka cycles (2nd- and 3rd-order); 3 — the chronostratigraphical scheme based on Gradstein *et al.*, 1995. For general lithofacies explanation see Fig. 67; for localities see Fig. 1

algae exchange and promote appearance of new forms — it might particularly regard the dinoflagellate cysts. Possibly, connections with the Tethys could provide an explanation why some dinoflagellate cysts seem to appear earlier in the German (Brenner, 1986) and Polish Basin (this paper) than in British and Danish areas (Poulsen, Riding, 2003). It particularly regards sparse appearances of some dinoflagellate cysts related to the maximum flooding surfaces — such as occurrence of *Liasidium variabile* Drugg near the maximum flooding surface of sequence I in Gorzów Wielkopolski IG 1 borehole, dated to the Middle Hettangian (Fig. 64 CD, depth 1112.0 m) or occurrence of *Mendicodinium* sp. (Gedl, pers. comm.) in the same borehole at the depth 1044.0 m, close to the maximum flooding surface of sequence II (dated to the Early Sinemurian). Possibly, these dinoflegellate cysts evolved in the Polish and eastern German basins, subsequently migrating westwards. However, this supposition remains theoretical until more data are revealed (Gedl, in prep.)

In the overlying highstand systems tract, sedimentation was dominated by aggradation/progradation in the Pomerania region, which led to development of relatively thick, stacked deposits of shallower nearshore depositional subsystems. In the Holy Cross Mts region, the progradational HST depositional systems were of more isolated character, which gave way to development of semi-closed lagoons, embayments and delta-plain/marsh deposits (Przysucha Ore-bearing Formation with characteristic sideritic horizons, Figs. 48: 3, 4; 71: 4). In the uppermost part of the highstand systems tract of depositional sequence I, a short-lived but relatively widespread flooding event occurred (parasequence Ik), documented by marine bivalve fauna (Pl. I, 7) and transgressive lithofacies succession (Pl. XII, 5; Głęboka Droga 2 borehole, depth 16.0–20.0 m, Fig. 37 CD). The flooding surface of parasequence Ik is quite widespread. It corresponds with the following lithofacies: the mudstone intercalation within coarse fluvial deposits in Pobiedziska IGH 1 borehole (depth 1554.0–1555.0 m, Fig. 63 CD); lagoonal mudstones with Acritarcha in Gorzów Wielkopolski IG 1 borehole (depth 1099.0 m, Fig. 64 CD); and with the nearshore/embayment facies in the Kamień Pomorski IG 1 borehole (depth 490.0–500.0 m, Figs. 32 CD; 65 — here the parasequence Ik is amalgamated with the underlying parasequence Ij). Moreover, this flooding episode may well correspond with the uppermost Hettangian deposits with *Liasidium variabile* Drugg dinoflagellate cysts in Germany (Brenner, 1986) and the flooding event in the Danish Basin (Nielsen, 2003 — his MFS 10). Deposition of the highstand systems tract of parasequence I was followed by the forced fall in sea level, which formed the sequence boundary of the next depositional sequence II.

Extensive data documenting sea level fluctuations from adjacent areas: Germany (Bloos, 1976), Southern Sweden (Pień- kowski, 1991b), Denmark (Gravesen *et al.*, 1982; Surlyk *et al.*, 1995; Nielsen, 2003), England (Donovan *et al.*, 1979; Hallam, 1997; Buchem, Knox, 1998; Hesselbo, Jenkyns,1998), France (de Graciansky *et al.*, 1998b) as well as those from Poland (the present paper) show clear relationship between the eustatic events and sedimentary evolution of Hettangian deposits. It was already postulated by the present author (Pieńkowski, 1991a). The transgressive systems tract (parasequences Ia–f, Zagaje Formation and Skłoby Formation) is associated with transgressive surface and its correlative conformity at the base of parasequence Ib (Figs. 26, 69). It is likely that this transgressive impulse occurred in the early *planorbis* Zone. Hallam (1997) estimated minimum rate of the earliest Hettangian sea level rise at about 1 cm in 0.2 ka (200 years), which shows that the pace of sea level rise was high (although the uncertainties of this calculation can be very large).

The highstand systems tract, associated with progradation and resulting regressive trends (Przysucha Ore-bearing Formation in Holy Cross Mts and the uppermost part of the Skłoby Formation in Pomerania region and Fore-Sudetic Monocline), can be correlated with Late Hettangian in Europe (Bloos, 1976; Pieńkowski 1991a, b). It is consistent with the Exxon curve (Haq *et al.*, 1987) and that presented by Hallam (1988), Hesselbo and Jenkyns (1998) and de Graciansky *et al.*, 1998b (their fig. 13). Nielsen (2003) introduced additional sequence boundary (his SB 10, placed at the beginning of *angulata* Zone) with ensuing minor sequence, and his figure 25 shows overall regressive tendencies in the *angulata* Zone in the Danish Basin. Assuming all that, the similarity of the sedimentary trends between the Polish Basin and other parts of Europe in Hettangian times is very conspicuous (Figs. 69, 70, 72).

The whole depositional sequence I is identified with the whole 2nd-order supercycle 1.1 of the Upper Absaroka megacycle of Exxon curve (Haq *et al.*, 1987) – Figs. 69, 72.

DEPOSITIONAL SEQUENCE II (EARLY SINEMURIAN)

An aggradational/progradational trend occurring in Late Hettangian times was followed by a period of forced regression in latest Hettangian to the Hettangian/Sinemurian boundary, or slightly later (Nielsen, 2003). Since recognition of seismic unconformities in the North Sea area (Vail, Todd, 1980), the forced sea level fall at the Hettangian/Sinemurian boundary (most probably, it occurred in the latest Hettangian in *complanata* Subzone — mid-*angulata* Zone), is confirmed by many authors (Haq *et al.*, 1987; Hallam, 1988; de Graciansky *et al.*, 1998b, and Hesselbo, Jenkyns, 1988). The sea level fall led to extensive erosion and associated sequence boundary. According to Hallam (1990), this world-wide regression caused a major turnover of Jurassic ammonoids — the forms belonging to the family Psiloceratidae and many Schlotheimiidae went extinct and were later replaced by Arietitidae. This interpretation is also consistent with data presented by Sandoval *et al.* (2001).

Above the sequence boundary, initial sedimentation of alluvial/deltaic sediments (lowermost part of the Ostrowiec Formation, parasequence IIa) formed a characteristic lithofacies in the entire Polish Basin, including the Mid-Polish Trough (Figs. 48: 5; 71: 5). Alluvial sediments commence the following transgressive systems tract (“pre-transgression” package of the transgressive systems tract, parasequence IIa). Erosion and following fluvial sedimentation is less conspicuous in the axial part of the basin —

Głęboka Droga 2 borehole (Figs. 37 CD; 40; 42). This initial alluvial sedimentation probably started at the same time when the earliest Sinemurian sea level rise, dated by Hesselbo and Jenkyns (1998) to *conybeari* Subzone (early *bucklandi* biochronozone). According to these autors, this transgressive impulse was followed by a sea level fall in early *rotiforme* Subzone, followed by another sea level rise (late *bucklandi* Zone). Rapid and frequent sea level changes in the *bucklandi* Zone could result in amalgamated alluvial-deltaic deposits in the Polish Basin (Figs. 48: 5; 71: 5), while in Southern Sweden it may be represented by shallow, brackish-marine facies ("Ostrea bank" — Troedsson, 1951; Pieńkowski, 1991b).

The following transgressive trend of the *semicostatum* Zone is widespread all over the world (Haq *et al*., 1987; Hallam, 1988; Buchem, Knox, 1998; Hesselbo, Jenkyns, 1998; de Graciansky *et al*., 1998b). Hesselbo and Jenkyns (1998) dated the beginning of major transgression at the *lyra* Subzone. De Graciansky *et al*. (1998b) dated maximum flooding surface of this transgression (their Si_1 sequence) at infra-*scipionianum* Subzone (middle *semicostatum* Zone), which is in good accordance with Haq *et al*. (1987). Interestingly, Hesselbo and Jenkyns (1998) marked two shallowing-deepening successions within their composite profile of *semicostatum* deposits, the upper accounting for the maximum flooding surface (their earliest deepening-shallowing cycle in the Early Sinemurian section would then correspond to the parasequence IIa). Their cycles could be identified as parasequences IIb and IIc of this paper (Figs. 42, 65, 72), with maximum flooding surface in parasequence IIc. In the Pomerania region, the maximum flooding surface is associated with development of the marine lithofacies (Fig. 65). Consequently, the following highstand systems tract (upper part of the parasequence IIc), associated with progradation of relatively thin nearshore, deltaic and barrier-lagoon lithofacies (Fig. 42; Fig. 64 CD, depth 1028.2–1047.0 m) would correspond to the upper *semicostatum–turneri* Zones. On the Wielkopolska region (Pobiedziska IGH 1, depth 1508.0–1554.0 m, Fig. 63 CD), sedimentation of the whole depositional sequence II is dominated by coarse, alluvial depositional system. It is likely that deposits of the whole parasequence IIc were removed by subsequent erosion (Fig. 63 CD).

Depositional sequence II is generally represented by the lower part of Ostrowiec Formation (Figs. 3, 42, 65, 69, 70), and it expands beyond the Mid-Polish Trough (Fig. 48: 6). On the Wielkopolska region, this sequence is represented entirely by alluvial deposits, thus the Zagaje Formation embraces also the Early Sinemurian there (Figs. 3; 63 CD). This sequence is considerably thicker in the Pomerania region than it is in the Holy Cross Mts region (Figs. 69, 70). Depositional sequence II is identified with the 3rd-order cycle 2.1 of the Upper Absaroka megacycle of Exxon curve (Haq *et al*., 1987) — Figs. 69, 72.

DEPOSITIONAL SEQUENCE III (LATE SINEMURIAN)

Erosion preceding sedimentation of this sequence is very conspicuous in the Holy Cross Mts region (Fig. 42), although the scale of erosion differs from place to place. In the Fore-Sudetic Monocline and Pomerania regions, the erosion was less conspicuous (perhaps due to the local tectonic regime) and a hiatus associated with emersion and palaeosol development occurred. The erosional base of the depositional sequence III is correlated with one of the major sequence boundaries which occurred in Early Jurassic in boreal Europe dated at the late *turneri* Zone (*birchi* Subzone) — Hesselbo, Jenkyns (1998), de Graciansky *et al*. (1998b).

The following deltaic (Fore-Sudetic Monocline and Pomerania regions) or alluvial (Holy Cross Mts — Fig. 48: 7) sedimentation represents a "pre-transgression" stage of the transgressive systems tract (parasequence IIIa). These sediments are rather thin, except perhaps in the Gródek area (Fig. 42), where preceding erosion created a larger accommodation space. Only in the Wielkopolska region did the alluvial sedimentation leave a coarser deposit (Pobiedziska IGH 1 borehole, depth 1490.0–1508.0 m, Fig. 63 CD). Initial alluvial/deltaic sedimentation would correspond with beginning of transgression in Europe (earliest *obtusum* Zone, early *obtusum* Subzone).

Following transgression (parasequence IIIb), dated at the mid-*obtusum* Subzone, was widespread and rapid (Fig. 48: 8), as in all areas studied basinal facies rest directly on alluvial/deltaic deposits. This is true also of the elevated Wielkopolska region (Pobiedziska IGH 1 borehole, depth 1489.5 m, Fig. 63 CD). The transgressive systems tract embraces parasequences IIIb and lower part of parasequence IIIc, arranged in a retrogradational succession (Figs. 42; 48: 8, 9; 65). A maximum flooding surface was associated with marine shelf sediments in Pomerania region, while in the Holy Cross Mts this stage is associated with strong marine influences (rich and diversified ichnofauna, marine palynofacies — Figs. 36 CD, depth 35.0 m; 42). Expansion of the basin far beyond the Mid-Polish Trough is evident: brackish-marine/marine lithofacies occur in Fore-Sudetic Monocline (Fig. 64 CD, depth 997.0 m) and Wielkopolska region (Fig. 63 CD, depth 1481.0 m). This expansion stage of the basin is shown on the palaeogeographical maps — Figs. 48: 9 and 71: 6. According to Hesselbo and Jenkyns (1998) and de Graciansky *et al*. (1998), the *obtusum* Zone transgressive phase was one of most significant ones of the Liassic Anglo-Paris Basin and is considered a 2nd-order transgression. Additional transgressive impulse in *obtusum/stellare* subzones transition could correspond to the parasequence IIIb maximum flooding. The maximum flooding surface of the whole depositional sequence III in Poland (parasequence IIIc, Figs. 48: 9; 71: 6) is correlated with one of major maximum flooding surfaces in Early Jurassic in Europe, dated by Hesselbo and Jenkyns (1998) at the *obtusum*/*oxynotum* zones transition.

The following highstand systems tract embraces the upper part of parasequence IIIc and parasequences IIId and IIIc, forming a progradational succession characterised by more and more pronounced development of barrier-lagoon and deltaic depositional systems upwards in the profile (Figs. 42; 48: 10).

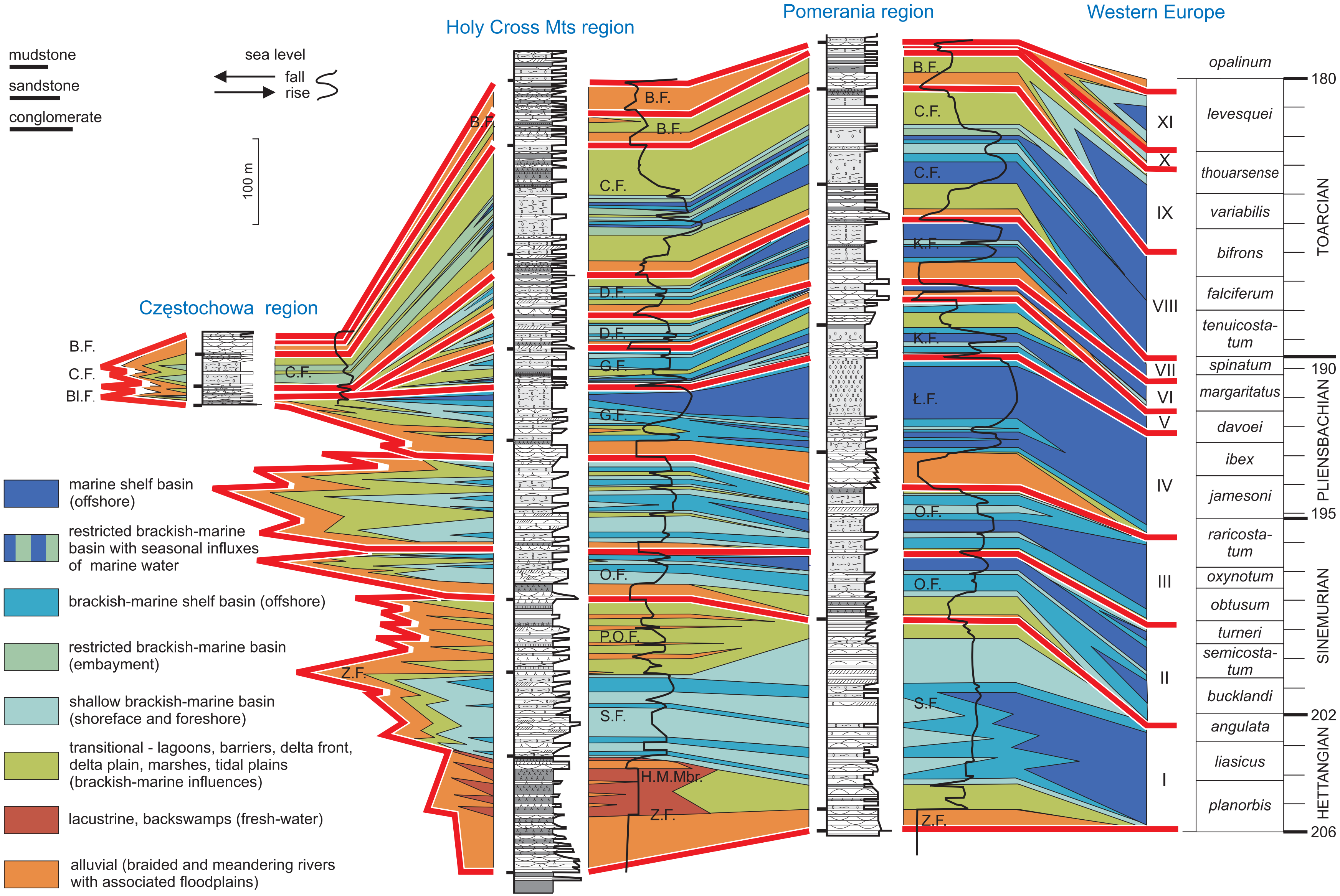


Fig. 70. Depositional architecture of the Early Jurassic basin in Poland showing dominant depositional systems and sequence stratigraphic correlation

Note that the high-frequency sea-level changes are better marked in shallow-marine and marginal-marine environments (Pomerania region–Holy Cross Mts region) than in the marine facies of West European basin. In the most marginal parts of the basin (Częstochowa region), many of the sequences are missing, other are strongly reduced and best correlative surfaces are provided by the most pronounced maximum flooding surfaces (Early Pliensbachian and Early Toarcian). Note, that the Polish section presents the real facies cross-section, while the schematic Western Europe profile shows only the time scale, major sequence boundaries and dominant facies. The legend explains generalised depositional systems. For general lithofacies explanation see Fig. 67

This highstand phase would correspond to *oxynotum* (*simpsoni–oxynotum* Subzone)–earliest *raricostatum* Zone — similarly as in France (de Graciansky *et al*., 1998b). Again, two conspicuous transgressive impulses marked by Hesselbo and Jenkyns (1998) within this section of the sea level curve would tentatively correspond to parasequences IIId and IIIe in the Polish Basin (Figs. 42, 69, 72). Depositional sequence III is represented by the upper part of Ostrowiec Formation in whole Polish Basin.

Sea level correlation between the Late Sinemurian European basins needs some comments. It should be reiterated that the sea level changes and sequence stratigraphy in the Polish Basin should be compared to North European (Boreal) realms, because correlation between Tethys realms and Boreal ones show some differences, for example in Sinemurian. It should be also noted that Hesselbo and Jenkyns (1998), in contrast to Hallam (1988) recognised an important *oxynotum* Zone deepening, casting some doubts on this section of Hallam's sea level curve.

Depositional sequence III is identified with the 3rd-order cycle 2.2 of the Upper Absaroka megacycle of Exxon curve (Haq *et al*., 1987) — Figs. 69, 72.

DEPOSITIONAL SEQUENCE IV (LATEST SINEMURIAN–EARLY PLIENSBACHIAN)

According to Hesselbo and Jenkyns (1998), the general sea level fall associated with recurrent hiatuses and erosion in the Lower Jurassic of the British area occurred in upper *raricostatum* Zone (*macdonelli* and *aplanatum* subzones). Also in France, the uppermost Sinemurian deposition is marked by an overall regression in both the Tethyan and Paris Basin areas (de Graciansky *et al*., 1998b). Transgressive impulse within this overall regressive period is also noted (Hesselbo, Jenkyns, 1998; de Graciansky *et al*., 1998b). Noteworthy, a major hiatus exists at the top of Sinemurian in Germany (Brandt, 1985) and the regressive Pankarp Member in Southern Sweden represents late Sinemurian (most probably mid-*raricostatum* Zone; Norling, 1972; Sivhed, 1984; Pieńkowski, 1991b). Haq *et al*. (1987) dated this sea level fall and sequence boundary to the mid-*raricostatum* Zone. De Graciansky *et al*. (1998b) dated it at the base of *aplanatum* Subzone (Si_5 sequence).

The regressive latest Sinemurian stage (or stages) is identified with the sequence boundary and conspicuous erosion, occurring in the Polish Basin at the bottom of depositional sequence IV (Holy Cross Mts — Figs. 42; 46; Wielkopolska region — Fig. 63 CD, depth 1463.5 m; Fore-Sudetic Monocline — Fig. 64 CD, depth 980.2 m; Pomerania region — Fig. 31 CD, depth 750.3 m). The sequence boundary is overlain by coarse clastic deposits, followed by sandstone lithofacies of alluvial depositional system (parasequence IVa, Fig. 71: 7), which are also correlated with latest Sinemurian of the Anglo-Paris Basin. Thus, the sequence boundary would be of the mid-*raricostatum* age which is in concordance with Haq *et al*. (1987) and Hesselbo and Jenkyns (1998).

Following transgression begins the most pronounced expansion of marine facies in the Polish Basin. According to Hesselbo and Jenkyns (1998), de Graciansky *et al*. (1998b) and Hesselbo *et al*. (2000), early *jamesoni* Zone (*taylori* Subzone) is associated with the major marine transgression and beginning of transgressive systems tract. Such is the case in the Polish Basin, although the earliest marine deposits in Pomerania region dated by ammonites are reported from the *polymorphus* and *brevispinum* Subzones (Dadlez, Kopik, 1972). Good ammonite documentation comes from the *jamesoni* Subzone, and the richest ammonite fauna was reported from the *ibex* Zone (*valdani* and *luridum* Subzones). The profile of Mechowo IG 1 (Fig. 31 CD) shows that the Early Pliensbachian transgression commenced with nearshore deposits (the whole parasequence IVb and lowermost part of the parasequence IVc). They may well represent *taylori*, *polymorphus* and *brevispina* Subzones. In such a scenario, the rapid *taylori* (basal *jamesoni* Zone) transgression of Anglo-Paris Basin would correspond to similar event in the Polish Basin, but the transgression itself was less rapid due to more marginal setting of the Polish Basin and a higher siliciclastic sedimentary input. Successive rise of sea level and development of transgression led to establishment of marine depositional systems in the Polish Basin. An open marine, shelf basin occurred in Pomerania (Łobez Formation), while shallow-marine basin dominated by nearshore depositional system (Gielniów Formation) continued along the Mid-Polish Trough, down to the Holy Cross Mts region (Figs. 46; 48: 11). The nearshore deposits (Gielniów Formation) occurred also beyond the Mid-Polish Trough in the Fore-Sudetic Monocline and Wielkopolska region (Fig. 71: 8). Somewhat more restricted marine-brackish marine conditions extended much further, to the Częstochowa region (Fig. 62: 1 — Blanowice Formation) and Baltic Syneclise (Figs. 66; 71: 8 — lower Olsztyn Formation). It proves extensive lateral range of the Early Pliensbachian transgression. As far as concerns character of sedimentation, it seems that in Pomerania quite stable shelf deposition occurred from later part of *jamesoni* Zone (*jamesoni* Subzone) to latest *ibex* Zone (*luridum* Zone: parasequence IVc), as evidenced by ammonite dating (Dadlez, Kopik, 1972) and lithofacies characteristics (this paper). Palynofacies analysis shows that shallowing or basin-isolation stage could have occurred below the faunally documented *luridum* Subzone (Kamień Pomorski IG 1 borehole, depth 265.0–268.0 m, Fig. 32 CD). It might represent a weak sea level fall reported by Hesselbo and Jenkyns (1998) from the British Lower Jurassic, dated at the *valdani* Zone. The evidence in support of a mid-*ibex* Zone relative sea level fall in the Polish Basin is also weak. Overlying deeper facies dated at the *luridum* Subzone would coincide with similarly deepening facies of *luridum* Subzone in England — which is, along with *taylori* Subzone, candidate maximum flooding zone in Early Pliensbachian (Hesselbo, Jenkyns, 1998). Assuming the presented facts, the present author regards the transgressive surface of depositional sequence IV (the base of parasequence IVb) as an equivalent of the maximum flooding surface in the *taylori* Subzone in the United Kingdom (*jamesoni* Zone), while the maximum flooding surface of depositional sequence IV (parasequence IVc) would correspond to the next maximum flooding surface in the United Kingdom, dated at the mid-*luridum* Subzone (*ibex* Zone). Thus, the deepening in the *jamesoni* Zone is fully confirmed, although the most diversified ammonite fauna point to the *luridum* Subzone as the one of a highest sea level in the Early Jurassic in Poland.

The following highstand systems tract is characterised by gradual regression in Pomerania region (upper part of parasequence IVc and parasequence IVd — Figs. 31 CD, 32 CD, 68–70). A similar progradational trend occurs in Fore-Sudetic Monocline (Gorzów Wielkopolski IG 1, depth 948.0–960.0 m, Fig. 64 CD), Częstochowa region (Figs. 55, 61) and in the Baltic Syneclise (Fig. 66 CD). In the studied fragment of the Holy Cross Mts region, the parasequence IVd has been largely removed by subsequent erosion (Fig. 46), but in places this progradation is well visible (Brody-Lubienia borehole, depth 270.0–275.0 m, Fig. 47 CD). The highstand systems tract would then correspond to the uppermost *ibex* Zone (uppermost *luridum* subzone) and lowermost part of *davoei* Zone, which shows similar character in United Kingdom (Phelps, 1985; Hesselbo, Jenkyns, 1998). In France, an additional sequence boundary (Pl_2) was distinguished in *masseanum* Subzone (lowermost *ibex* Zone), and consequently two maximum flooding surfaces were differentiated (in *jamesoni* and *luridum* subzones; de Graciansky *et al*., 1998b).

Depositional sequence IV is identified with the 3rd-order cycle 3.1 of the Upper Absaroka megacycle of Exxon curve (Haq *et al*., 1987) — Figs. 69, 72.

DEPOSITIONAL SEQUENCE V (LATE EARLY PLIENSBACHIAN) — *DAVOEI* ZONE

This sequence is well-defined in the Holy Cross Mts region, where an erosional sequence boundary is overlain by sandstone alluvial facies (parasequence Va) and can be traced over long distance (Figs. 46; 47 CD, depth 270.0 m). In the Wielkopolska region this boundary is even more conspicuous — the whole underlying parasequence IVd was removed and the sequence boundary is covered by conglomeratic alluvial deposits. In the Częstochowa region the whole of sequence V is difficult to recognise — it is amalgamated within alluvial deposits representing three sequences, or is eroded away (Figs. 55, 61). The erosional sequence boundary is less conspicuous in Pomerania region (Fig. 31 CD), and the whole sequence is thickest in this region. An ensuing transgression led to development of a nearshore depositional system in the Mid-Polish Trough (parasequences Vb), where the maximum flooding surface is placed (Figs. 46; 71: 9). Beyond the Mid-Polish Trough, nearshore deposition reached part of the Fore-Sudetic Monocline and Wielkopolska region. The following deposition is represented by highstand systems tract deposits, divided in Pomerania region (Fig. 31 CD) into two progradational parasequences Vb and Vc (plus the upper part of the parasequence Vb).

Depositional sequence V is identified with the 3rd-order cycle 3.2 of the Upper Absaroka megacycle of Exxon curve (Haq *et al*., 1987) — Figs. 69, 72. Comparison with the relative sea level curve of Hesselbo and Jenkyns (1998) allows identification of the sea level fall at the base of *capricornus* Subzone as a probable equivalent of the sequence V lower boundary, while a sea level rise recorded between *capricornus* and *figulinum* Subzones may correspond to the maximum flooding surface. It would correspond to sequence Pl_3 (de Graciansky *et al*, 1998b). It should be pointed out, that possible sea level correlation with the Western Europe are not very clear, as those changes were rather less conspicuous at that time.

DEPOSITIONAL SEQUENCE VI (LATE PLIENSBACHIAN) — EARLY–MID *MARGARITATUS* ZONE

The sequence boundary of depositional sequence VI is characterised by most prominent erosion among all the sequence boundaries in the Lower Jurassic of Polish Basin. It points to a significant sea level fall, associated with erosional removal of underlying deposits. Usually the upper parasequences of the depositional sequence V were eroded (Fig. 46), in some places the whole of sequence V was eroded away (Figs. 55; 61). In the Baltic Syneclise area, the fall of base level caused grooving/retrogressive erosion in sediment source area, which is proved by change of the sandstone provenance. Presence of coarse alluvial lithofacies in the centre of the Mid-Polish Trough (Fig. 31 CD, depth 494.0–515.2 m; Fig. 32 CD, depth 120.0–135.0 m) points that at the sequence boundary the whole Polish Basin was dominated by erosion and non-deposition. Therefore the Fig. 71: 10 shows a little bit later stage (initial stage of transgressive systems tract), when a rising base level allowed alluvial deposition in the Mid-Polish Trough. The sequence VI lower boundary provides one of the most significant correlative surfaces in the Polish Basin, particularly in the basin centre.

Certainly, this sequence boundary has to be correlated with the base of the 2nd-order cycle 4.1 of the Upper Absaroka megacycle of Exxon curve (Haq *et al*., 1987) — Figs. 69, 72. The bottom of this cycle is associated with the only type-I sequence boundary in Lower Jurassic, which is dated at the boundary between *davoei* and *margaritatus* Zones. The relative sea level curve of Hesselbo and Jenkyns (1998) is also closely comparable. According to these authors, the sea level

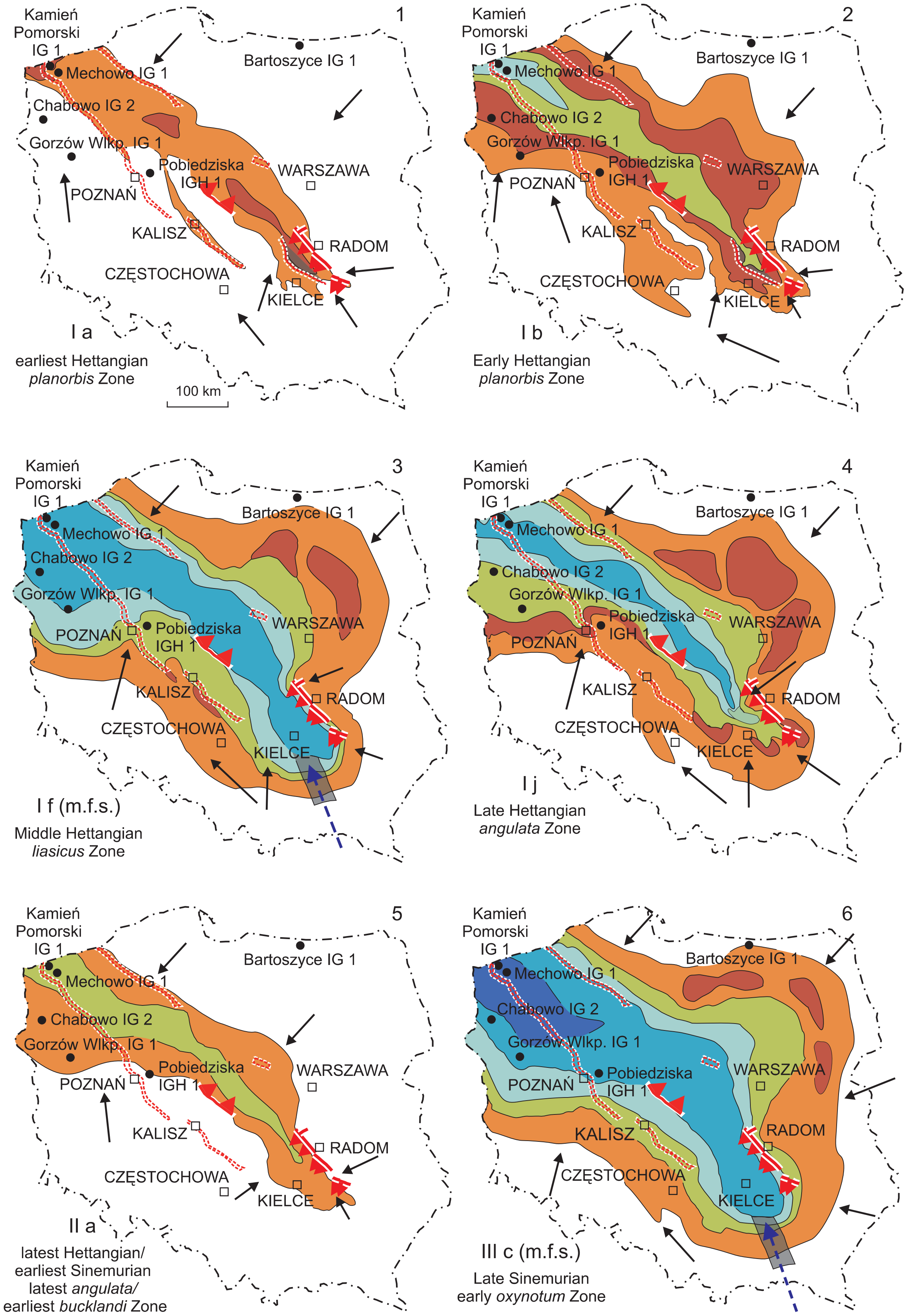
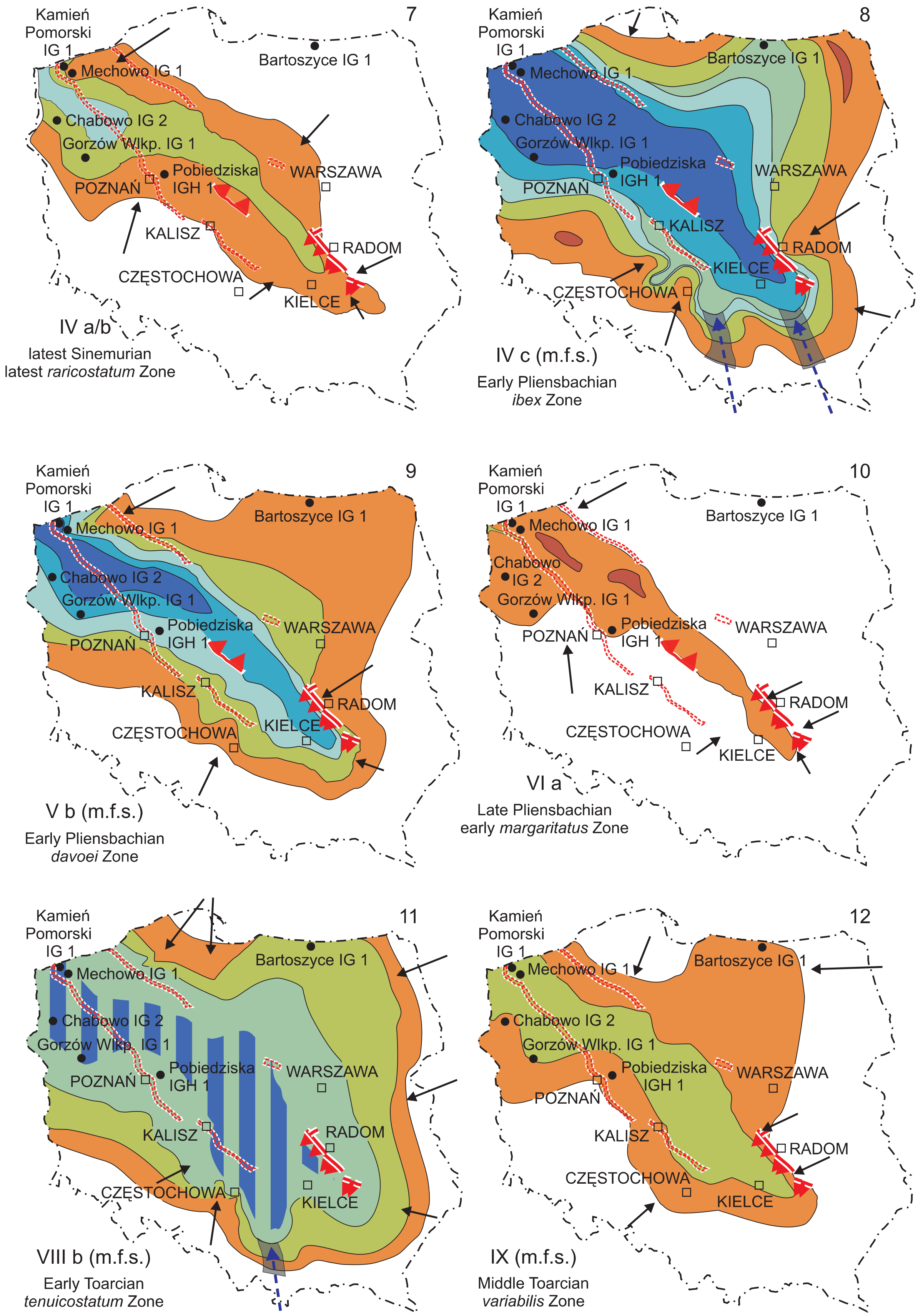


Fig. 71. Development of the Early Jurassic depositional systems

Note recurrent expanding and shrinking stages of the basin caused by sea level changes and conspicuously higher subsidence rate in the Mid-Polish Trough. boundaries (in such cases the maps would be "blank" or nearly "blank"), but they show the stages related to the initial ("pre-transgression") deposition navy-blue arrows. For explanation of the generalised depositional systems see Fig. 70



in the epicontinental Polish Basin (generalised)

The shrinking phases presented in the figure do not exactly correspond to the lowest sea level stages associated with maximum erosion at the sequence associated with basal transgressive systems tracts of overlying sequences. Hypothetical short-lived connections with the Tethys Basin are marked with dashed, fall at the *davoei/margaritatus* Zone transition was fast and the sea level was at its lowest point in the Early Jurassic times (Fig. 69). Similarly, Nielsen (2003) marks a sequence boundary in the Danish Basin (his SB 14) between *davoei* and *margaritatus* Zones. Results from France are less clear, but this sea level fall would correspond to the base of short-lasting Pl_4 or Pl_5 sequence, dated at the latest *figulinum* Subzone (latest *davoei* Zone) or earliest *stokesi* Subzone, respectively (de Graciansky *et al.*, 1998b).

The rapid sea level fall was followed by equally rapid sea level rise, which led to restoration of nearshore depositional systems in the Mid-Polish Trough (Figs. 46; 48: 12; Pl. XIII, 4, 5). Maximum flooding surface (parasequence VIb) would correspond to the latest *stokesi*/earliest *subnodosus* Subzone transition (Hesselbo, Jenkyns, 1998) and the following highstand systems tract (parasequence VIc) would correspond with the *subnodosus* Subzone. It is confirmed by the ammonite *Amaltheus* (?*Proamaltheus*) cf. *wertheri* Lange found in Chabowo IG 2 borehole (Fig. 68). The whole depositional sequence VI of the Polish Basin would then correspond to the sequences Pl_4, Pl_5 and Pl_6 of de Graciansky *et al*. (1998b). The accommodation space created by erosion at the *davoei/margaritatus* zones transition and subsequent significant and rapid sea level rise created accommodation space that allowed sedimentation in the Polish Basin, which could reach some 30 m (Fig. 45 CD).

DEPOSITIONAL SEQUENCE VII (LATEST PLIENSBACHIAN) — LATEST *MARGARITATUS–SPINATUM* ZONES

The erosional sequence boundary is well exposed in the Śmiłów quarry (Pl. XIII, 3, 4, 7) and can be identified in the whole Polish Basin, thanks to overlying alluvial deposits (Figs. 69, 70, 72). It would correspond to the base of Pl_7 sequence according to de Graciansky *et al*. (1998b) and to an abrupt coarsening of sediments associated with sequence boundary, occurring in the *gibbosus* Subzone (late *margaritatus* Zone) — Hesselbo and Jenkyns, 1998. The following transgressive systems tract of depositional sequence VII would comprise deposits of the latest *margaritatus*–early *spinatum* Zone (late *gibbosus–apyrenum* Subzone), with maximum flooding surface in lower/middle part of *apyrenum* Subzone (*spinatum* Zone). In Poland the age is documented by ammonites (Dadlez, Kopik, 1975). Such a scheme fits well to the sequence stratigraphy of United Kingdom (Hesselbo, Jenkyns, 1998) and France (de Graciansky *et al*., 1998b). The highstand systems tract would correspond with upper part of *apyrenum* Subzone and lower part of *hawskerense* Subzone.

Deposits of this sequence have a wide regional extent — marginal-marine deposits occur far beyond the Mid-Polish Trough, reaching Częstochowa region (Figs. 55, 61, 62: 2). Alluvial deposition occurred in the Baltic Syneclise (Fig. 66 CD).

The depositional sequence VII is identified with the 3^{rd}-order cycle 4.2 of the Upper Absaroka megacycle of Exxon curve (Haq *et al*., 1987) — Figs. 69, 72.

DEPOSITIONAL SEQUENCE VIII (EARLY TOARCIAN)

The erosional sequence boundary, which occurs in the Polish Basin, can be identified with the Pl_8 sequence boundary (de Graciansky *et al*., 1998b) and the sequence boundary reported by Hesselbo and Jenkyns (1998). This has been dated at the late *hawskerense* Subzone (latest *spinatum* Zone). It was followed by sea level rise in the *tenuicostatum* Zone. According to Haq *et al*. (1987), Hallam (1988; 1997) and Hesselbo and Jenkyns (1998), this transgression was of a linear trend, culminating in maximum flooding surface, placed between the early *falciferum* Zone (*exaratum* subzone) to *falciferum/bifrons* biochronozonal transition. According to de Graciansky *et al.* (1998), in Paris Basin the maximum flooding surface occurred slightly later, in the *bifrons* Zone. However, in Paris Basin the section between the base of *tenuicostatum* Zone and the *bifrons* Zone is subdivided into sequences Pl_8, To_1, To_2 and To_3 , with additional (3^{rd} order) maximum flooding surfaces occurring in *clevelandicum* and *strangewaysi* Subzones of *tenuicostatum* Zone. According to Hallam (1988, 1997), the Early Toarcian maximum flooding surface (he placed it in the *falciferum* Zone) is one of the best authenticated eustatic events in the Jurassic, marked by evident deepening in marine successions and marine transgression in extensive parts of the world. It is also marked by an Early Toarcian oceanic anoxic event, associated with the widespread deposition of organic-rich shales (Jenkyns, 1988).

Similarly, the Early Toarcian transgression in Poland was extensive and it also reached the marginal parts of sedimentary basin (Fig. 71: 11). It occurred during deposition of parasequences VIIIb and VIIIc. The age of parasequence VIIIb likely represents the *tenuicostatum* Zone, as evidenced by finds of dinoflagellate (Barski, Leonowicz, 2002) — *Luehndea spinosa* (Morgentoth) combined with finds of megaspores (Marcinkiewicz, 1971, 1988).

Where the maximum flooding surface is defined within the parasequence VIIIb (*tenuicostatum* Zone), it does not match the age of maximum flooding surface of the Exxon's curve (Haq *et al*., 1987), or the age of maximum flooding surface postulated by Hallam (1997), Hesselbo and Jenkyns (1998) and de Graciansky *et al.* (1998b). If the maximum flooding surface is placed within the VIIIc parasequence of the Polish Basin (Fig. 72), it may well correspond with the maximum flooding surface of the European basins, usually dated at the late *falciferum* Zone or *falciferum/bifrons* biochronozonal transition. Such "shifting" position of the maximum flooding surface in the Polish Basin (Figs. 55, 61) is associated with

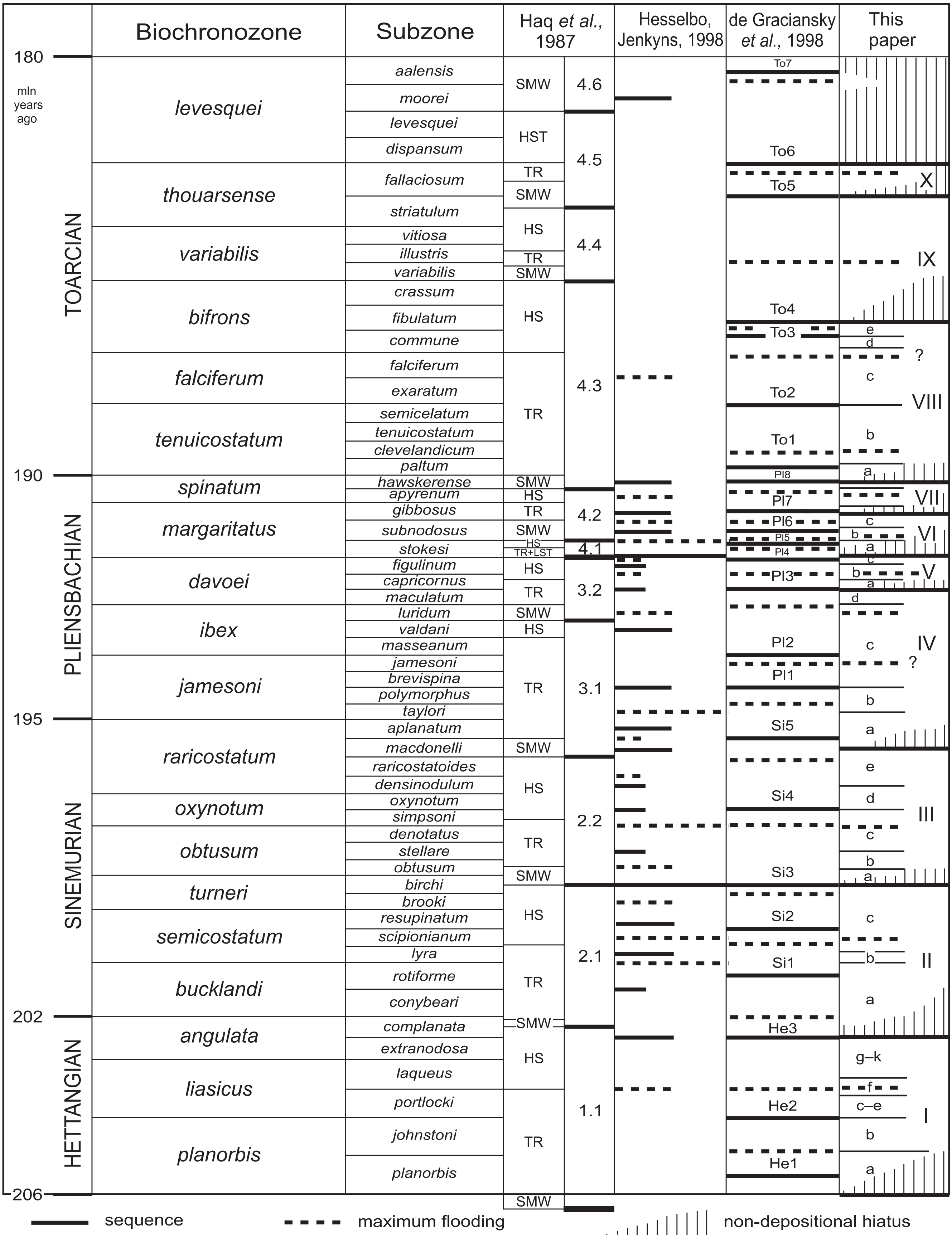


Fig.72. Sequence stratigraphic correlation between Western Europe (Haq *et al*., 1987; Hesselbo, Jenkyns, 1998; de Graciansky *et al*., 1998) and the Polish Basin

approximately similar sea level in parasequences VIIIb and VIIIc, separated by a shallowing stage. The shallowing stage is sometimes associated with nearshore-deltaic-marshy deposits, sometimes — in marginal parts of the basin — with palaeosol horizons. Plant roots and emersion/palaeosol surfaces occur in the Wręczyca 3/81 borehole (Fig. 54 CD) and in Suliszowice 38 BN (Fig. 56 CD). Such "interruption" of the transgressive trend in the lower Toarcian is not shown on the Exxon curve and on the sea level curve from the United Kingdom (Hesselbo, Jenkyns, 1998). However, it was reported from the Paris Basin (de Graciansky *et al*., 1998b) and, most importantly, from the adjacent German Basin (Röhl *et al*., 2001) where the *tenuicostatum* Zone flooding is of the same magnitude as the flooding of *falciferum/bifrons* biochronozonal transition. Both flooding stages in Germany are separated by a shallowing period, dated at the lower *falciferum* Zone. This shallowing would correspond with the base of To_2 sequence from France (de Graciansky *et al*., 1998b). Therefore, it is fully justified to compare development of the Early Toarcian transgression in Poland with that from Germany (Röhl *et al*, 2001). Consequently, some differences between these two basins and the rest of Europe would occur. The shallowing period, separating otherwise "linear development" of the transgression, could be simply overlooked or impossible to observe in deeper marine facies. Moreover, comparison between individual basins in Western Europe shows generally marine conditions throughout *tenuicostatum–bifrons* times, but stratigraphical position of the maximum flooding surface varies from place to place between early *falciferum* and early *bifrons* Zones. Assuming influence of coeval epeirogenic movements occurring in the vast area of German and Polish basins, without effects in the Anglo-Paris Basin and North Sea Basin, seems to be rather unrealistic. Shift in sediment supply could influence the bathymetry of the basin, particularly in Poland, where it was shallow. However, it would be rather of a local scale. Assuming all that, it is advisable to accept, that the apparent effects of shallowing/deepening phases are most marked in the shallow facies and they are less elaborate when inferred from deeper water facies. Therefore, the detailed pattern of sea level changes inferred from the Polish Basin and correlated with more precisely dated sedimentary succession from the German Basin (Röhl *et al*, 2001) provides more detailed information concerning the actual sea level changes, than those inferred from the deeper marine basins.

It is advisable to correlate the transgressive surface in the Polish Basin with the base of *tenuicostatum* Zone, while the sequence stratigraphic correlation of the maximum flooding surface seems to be more complicated (either in VIIIb or VIIIc parasequence). Perhaps, it would be advisable to propose subdivision of the Early Toarcian deposits into two sequences with two maximum flooding surfaces, but than these sequences would not be clearly separated by a marked sequence boundary associated with a pronounced effect of sea level fall.

It also regards the highstand systems tract, which would correspond to the whole *bifrons* Zone of the Exxon curve (Haq *et al*., 1998) or to the early *bifrons* Zone according to de Graciansky *et al*. (1998b). In Poland, it is divided into VIIId and VIIIe parasequences. Depending on position of the maximum flooding surface, parasequence VIIIc and the upper part of parasequence VIIIb may also be regarded as highstand systems tract. Parasequences VIIIc, VIIId and VIIIe are generally of a shallowing-upward character, shown by denser and denser palaeosol horizons, plant roots and plant debris, more landward palynofacies and gradually decreasing boron content. However, flooding surfaces of parasequences VIIIc and VIIId are still quite pronounced in the axial part of the Mid-Polish Trough (Figs. 31 CD, 47 CD).

The depositional sequence VIII is identified with the 3^{rd}-order cycle 4.3 of the Upper Absaroka megacycle of Exxon curve (Haq *et al*., 1987) — Figs. 69, 72.

DEPOSITIONAL SEQUENCE IX AND X (MIDDLE–LATE TOARCIAN)

In the Polish Basin, a conspicuous erosional boundary occurs above deposits of depositional sequence VIII. The erosion surface is overlain by alluvial deposits (parasequence IXa), which covered the whole Polish Basin (in the axial parts of the Mid-Polish Trough they can be replaced by deltaic deposits). The sequence boundary and following alluvial/deltaic deposits are correlated with the base of 3^{rd}-order cycle 4.4 of the Exxon curve (Haq *et al*., 1987), dated at the early *variabilis* Zone. According to de Graciansky *et al*. (1998b) the sequence boundary should be dated slightly earlier, to the late *bifrons* Zone.

The overlying deltaic deposits (parasequence IXb, transgressive systems tract) are associated with base level rise, dated by Haq *et al*. (1987) at the lower/mid-*variabilis* Zone. De Graciansky *et al*. (1998b) came to a similar conclusion (transgressive systems tract and maximum flooding surface of the To_4 sequence). It should be noted that deltaic deposition associated with a flooding event is generally restricted to the Mid-Polish Trough (Fig. 71: 12), although deltaic deposition reached briefly a small part of the Częstochowa region (Fig. 62: 4) and possibly northernmost part of the Fore-Sudetic Monocline. The overlying fluvial deposits would represent the progradational highstand systems tract, tentatively correlated with the *variabilis*–early *thouarsense* Zone (highstand systems tract of the To_4 sequence — de Graciansky *et al*., 1998b).

Depositional sequence IX is identified with the 3^{rd}-order cycle 4.4 of the Upper Absaroka megacycle of Exxon curve (Haq *et al*., 1987) — Figs. 69, 72.

Overlying sediments of the depositional sequence X overlie the next erosional boundary and they are entirely alluvial in origin. The erosional lower boundary is tentatively correlated with the base of 3^{rd}-order 4.5 cycle of the Exxon curve (Haq *et al*., 1987). Alluvial deposition ending the Early Jurassic sedimentation in the Polish Basin would correspond with 4.5 cycle of the Exxon curve (Haq *et al*., 1987) or To_5 sequence (late *thouarsense* Zone, de Graciansky *et al*., 1998b). It is likely that alluvial deposits in the Polish Basin would represent mainly transgressive systems tract (particularly maximum flooding surface sediments) of that sequence. As Late Toarcian times is characterised by a progressive, overall sea level fall (Hesselbo, Jenkyns, 1998), it is a logical conclusion that the sedimentation in marginal basins is represented by alluvial sediments, restricted in time and space. Consequently, the depositional seuence X in the Polish Basin would represent the late *thouarsense* Zone (Figs. 69, 72).

Beginning of the next sequence would still fall within the latest Toarcian (late *levesquei* Zone), which corresponds with the base of 4.6 cycle of the Exxon curve (Haq *et al*., 1987). As the base of this cycle represents the shelf margin wedge deposits (SMW), it is regarded as an erosional/non-deposition period in the Polish Basin. It would span quite a long time, according to Haq *et al*. (1987) and de Graciansky *et al*. (1998b) the upper half of the long-lasting *levesquei* Zone (from the *insigne* Subzone or To_6 sequence base upwards). In the Polish Basin, this sequence boundary would merge with the sequence boundary of *aalensis* Subzone (To_7 sequence boundary — de Graciansky *et al*., 1998b) or even with the (type 1) sequence boundary in Early Aalenian (Haq *et al*., 1987). Consequently, the deposits overlying the uppermost sequence boundary in Lower Jurassic of Poland would represent the Middle Jurassic age.

SUMMARY AND CONCLUSIONS

Comparison between sea level changes in Poland (inferred from arrangement of depositional sequences and parasequences within a biostratigraphical framework) and sea level changes in adjacent areas (Sweden, Germany), as well as comparison with other European (Ligurian Cycle — Hesselbo, Jenkyns, 1998; de Graciansky *et al*., 1998b, Denmark — Frandsen, Surlyk, 2003; Nielsen, 2003 — the latter with some differences in Sinemurian), or world-wide sea level changes (Upper Absaroka Megacycle — Exxon curve — Haq *et al*., 1987), allows presentation of a coherent and detailed stratigraphy of the epicontinental Early Jurassic deposits in Poland (Figs. 69–72). The Polish Basin was connected with the West European basin chiefly through the Northern Germany, Southern Sweden and Denmark (Fig. 1), but episodic connections with the Tethys were also possible (Fig. 71).

The sequence correlation of the Polish Basin is not based on individual (local) deepening-shallowing cycles, which were produced by number of factors, including local tectonic processes, but on regional trends of relative sea level change. These trends are dated stratigraphically on the basis of palaeontological evidence with varying degrees of precision. However, the close similarity between trends of relative sea level change and continuity of correlative surfaces over the whole area studied allowed quite precise sequence stratigraphy and advocates an super-regional sea level changes as primary sedimentation-controlling factor.

Coeval or approximately coeval character of major fluctuation in sea level related sedimentation in the Early Jurassic of Poland is confirmed by similarities of depositional sequences observed between the Polish Basin and basins in Western Europe (United Kingdom and France) as well as the Exxon curve. Regardless of discussion of the character of the sea level changes (eustatic or intraplate tectonic-related), the relative sea level curves from Western Europe (Hesselbo, Jenkyns, 1998) as well as depositional sequence succession (de Graciansky *et al*., 1998a, b) provide a very useful tool for stratigraphic correlation. On that basis, the Early Jurassic epicontinental basin in Poland, containing sediments only sporadically dated by ammonites, could be "attached" to the European stratigraphical framework. Striking similarities with relative sea level curves (particularly that of Hesselbo, Jenkyns, 1998) allows determination of even minor and short-lived events. As the Polish Basin was extensive and shallow, it was prone to reflect even minor relative sea level changes. Apparent effects of these changes are usually most marked in the shallowest water facies.

Therefore, results of the present work may be helpful in recognition of magnitude, and sometimes even of direction of individual sea level related sedimentary changes in open-marine basins in Europe. It is a known dilemma that, if linked to sea level, then condensation within medium-scale cycles in distal settings may be a consequence of relative sea level fall, as well as rise (Hesselbo, Jenkyns, 1998; sediment starvation — sedimentary winnowing/hiatus dilemma). Moreover, the structure of the relative sea level curve is strongly influenced by the superposition of medium-scale cycles upon large-scale cycles; it is simply less elaborate when inferred from deeper water facies.

Concerning the magnitude of sea level changes, inferred from the sedimentary architecture of the Polish Basin, the number of depositional sequences, characterised by truly basin-wide range and unambiguous, well-identified boundaries seems to be identical with those ten distinguished by Haq *et al*. (1987). However, most of the minor sea level changes and sequences distinguished by Hesselbo and Jenkyns (1998) correspond to the parasequences identified within the mentioned 10 depositional sequences in the Polish Basin (Fig. 72), particularly in the Sinemurian and Pliensbachian. Major sea level falls in the Polish Basin (shrinking phases of the basin), associated with large-scale ("2^{nd}-order") cycles of Haq *et al*. (1987) and Hesselbo and Jenkyns (1998), are identified with the following stages:

— latest Hettangian (latest *angulata* Zone — Fig. 71: 5),
— Late Sinemurian (latest *turneri*–early *obtusum* Zone),
— latest Sinemurian (mid-*raricostatum* Zone — Fig. 71: 7),
— late Early Pliensbachian (earliest *davoei* Zone),
— earliest Late Pliensbachian (transition latest *davoei*–earliest *margaritatus* Zone),
— mid-Late Pliensbachian (late *margaritatus* Zone),
— latest Pliensbachian (late *spinatum* Zone),
— MiddleToarcian (late *bifrons*–early *variabilis* Zone),
— Late Toarcian (mid-*thouarsense* Zone),
— Latest Toarcian (late *levesquei* Zone).

On the other hand, maximum sea level stages, associated with expanding phases of the Polish Basin occurred in:
— Middle Hettangian (*mid-liasicus* Zone) – Fig. 71:3),

— Early Sinemurian (mid-*semicostatum* Zone),
— mid-Late Sinemurian (early *oxynotum* Zone) — Fig. 71: 6,
— Early Pliensbachian (late *ibex* Zone) — Fig. 71: 8,
— Late Pliensbachian (early *spinatum* Zone),
— Early Toarcian (depending on the region, *tenuicostatum* or *falciferum* Zone) — Fig. 71: 11,
— Middle Toarcian (disputable — *mid-variabilis* Zone) — Fig. 71: 12.

Short-term, 3rd-order or 4th-order cycles are superimposed on those major sea level fluctuations (Fig. 72). Particularly clear is the Hettangian section, which shows a characteristic "step-wise" development of transgression in the Polish Basin. The earliest Hettangian transgression gives a good example of the continental correlative surface of transgression. This transgression (dated in Western Europe at the *psilonotum/johnsoni* subzonal transition) is correlated with the transgressive surface in Pomerania (Fig. 31 CD) or with the continental correlative surface of transgression in the Holy Cross Mts. The continental correlative surface of transgression is associated with beginning of sedimentation of the lacustrine, "pre-transgressive" deposits (Figs. 24, 25, 39). The early Hettangian transgression culminates in maximum flooding surface correlated with the early-mid *liasicus* Zone (Figs. 29, 39). The following progra- dational highstand systems tract (parasequences If–k) corresponds to the late *liasicus*–early-mid *angulata* Zones (Fig. 40). Noteworthy, such sequence stratigraphy and sedimentary architecture development is very similar to that presented from the Hettangian of the Paris Basin (de Graciansky *et al*., 1998b — their fig. 13).

Similarly, the Sinemurian sequences and parasequences from the Polish Basin show close similarities to those presented by Hesselbo and Jenkyns (1988), including even in the number of parasequences identified with their minor sequences. Assuming correlation of the Polish Sinemurian with ammonite-bearing strata from Southern Sweden (Pieńkowski, 1991a, b), the present work fully supports the view of Hesselbo and Jenkyns (1998) and de Graciansky *et al*. (1998) that the important deepening occurred at the *obtusum/oxynotum* zonal transition (contrary to Hallam, 1988). On the other hand, the evidence in support of a mid-*ibex* Zone relative sea level fall in the Polish Basin is weak. However, deepening in the *jamesoni* Zone is fully confirmed. In the Polish Basin, relative sea level rose rapidly during the *jamesoni* Zone, then the sea level rise decelerated, although the most diversified ammonite faunas point to the *ibex* Zone (*luridum* Subzone) as the one of a highest sea level in the Early Jurassic in Poland. In this exceptional case, the Polish Pomerania Basin was probably too deep to register minor sea level changes in later *jamesoni*–*ibex* Zones.

Rapid and pronounced sea level fall at the *davoei/margaritatus* zonal transition is one of the major sedimentary events in the Polish Basin. This is in accordance with Exxon curve and the only Ist-type sequence boundary in the Early Jurassic times.

Depositional system development and ammonite finds points to the early-mid *margaritatus* and particularly early *spinatum* Zones as the times of pronounced marine transgresions.

Sequence/depositional systems architecture of the Early Toarcian deposits of Poland shows, that sequence correlation with the nearest German Basin (Röhl *et al*., 2001) is of primary importance for solving the sedimentary development problems. Maximum flooding stages of parasequences VIIIb and VIIIc (*tenuicostatum* Zone and late *falciferum* Zone, respectively) are of a very similar magnitude in the Polish Basin and very subtle, local factors can determine, which one should be defined as the maximum flooding surface of the whole sequence VIII. This sedimentary pattern of both Polish and German basins differs from the "linear" style of the Early Toarcian transgression (Haq *et al*., 1987; Hesselbo, Jenkyns, 1998). It provides further evidence that the apparent effects of shallowing/deepening phases are most marked in the shallow facies and they are less elaborate when inferred from deeper water facies.

Sea level fall and the resulting erosional boundary occurring at the *bifrons/variabilis* zonal transition is much more pronounced in Poland in comparison to Western Europe. Again, this could also be the result of the general shallow and marginal character of the Polish Basin. The same applies at the Upper Toarcian erosional boundary, which might correspond to the mid-*thouarsense* Zone.

Local tectonism could influence the regional sedimentation (change of local subsidence and thickness, creation of an additional accommodation space, renewed erosion, supply of coarser material) but was still not strong enough to determine the essential trends in the sedimentary development (Figs. 25, 39, 46, 70). Influences of local tectonism are limited to certain zones, while the effects of sea level changes can be observed in a much wider spatial extent. This is the most important feature allowing differentiation between sedimentary architecture influenced by local tectonism and sea level changes — see the examples presented in Figs. 25, 39, 46, 48. Early Jurassic times in Poland were characterised by generally weak synsedimentary tectonism. However, some local tectonic structures played more important roles. The Nowe Miasto–Iłża fault (Hakenberg, Świdrowska, 1997), which constituted the northeastern boundary in the Holy Cross Mts segment of the Mid-Polish Trough was active in the Early Jurassic times. This fault influenced sedimentation along the North-East margin of the Holy Cross Mts region (Fig. 48). Recurrent activity of this fault, in the Hettangian–Sinemurian times coupled with a much lesser activity of the parallel Skrzynno fault, produced coarser and somewhat thicker, but spatially limited deltaic sediments in Hettangian (Fig. 39 — in the region of Zawada, parasequences Id, Ih, Ii and Ij), Late Sinemurian (Fig. 42, region between Mroczków-Kraszków 160 and Gródek OP-2, parasequence IIIa and IIIc) and Early Pliensbachian (Fig. 46, Szydłowiec area, parasequence IVb — Wola Korzeniowa Member). Activity of other faults (like the local Ostrowiec fault or the N–S fault running through Końskie — Fig. 20) is documented in the Hettangian times (Figs. 25, 29).

Results of the present work show some subsidence fluctuations along the Mid-Polish Trough between the Holy Cross Mts region and Pomerania region. Such fluctuation (Figs. 69, 70) occurred in Hettangian, Early Sinemurian and Early Pliensbachian times. In the Hettangian subsidence was higher in the Holy Cross Mts and slightly lower in Pomerania region. In Early Sinemurian times the situation was opposite. In the Early Pliensbachian times, the subsidence rate was higher again in the Pomerania region. This extends conclusions of Wagner *et al*. (2002) that subsidence rate in Mesozoic was varied between individual segments of the Mid-Polish Trough (Pomeranian segment–Kuiavian segment–Holy Cross Mts segment).

Low subsidence rate beyond the Mid-Polish Trough resulted in sharply reduced thickness or lack of Hettangian–

Sinemurian deposits (Figs. 67–70). However, in the area of generally low subsidence (beyond the Mid-Polish Trough), some zones of higher subsidence rate appear. Besides the slight "secondary depocentre" in the Kalisz area (Fig. 71: 1, 2, 4; Poprawa, 1997), the extension of the marine/brackish marine facies to the north-east is very conspicuous. This occurred particularly in Early Pliensbachian and Early Toarcian times (Fig. 71: 8, 9, 11). Persistence of this northern "Mazurian way", conductive for expanding of basinal facies, was indicated by Wagner (1998) as "Peribaltic Bay" in the Late Permian times and by Leszczyński (1998) for the Late Valanginian. The boundaries between the Mid-Polish Trough and areas of low subsidence are characterised by a gradual thickness increase towards the axis of the Mid-Polish Trough (Dadlez *et al*., 1995; Dadlez, 2001). Only along some sections of the boundary the gradients of thickness are more pronounced (Chojnice Graben, part of Laska-Poznań Graben, part of Kalisz–Kamieńsk Graben — Dadlez, 2001) and particularly the Nowe Miasto–Iłża Fault. Displacement of rock salt masses of the Late Permian age, both taking place mainly at the end of Late Toarcian, resulted in formation of paleostructures of different order, whose characteristic general arrangement follows the NW–SE orientation (Deczkowski, Franczyk, 1988).

A gradual thickness increase towards the axis of the Mid-Polish Trough prevails across the edges of the Mid-Polish Trough (Dadlez *et al*., 1995; Dadlez, 2001), which can be also explained by a decoupled style of the sedimentary basin (Withjack, Calloway, 2000; Krzywiec, 2002).

Assuming occurrence of some conspicuous zones of increased subsidence, which are actually perpendicular to the Mid-Polish Trough (for example the "Mazurian way"), I fully agree with the mentioned authors, that there is no reason to regard the Mid-Polish Trough in any respect as a "rift basin" (Kutek, 1996), at least in the Early Jurassic times.

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