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The main stages of sedimentary development of the shallow-water carbonate platform of the Late Jurassic: A case study of the marginal zone in north-eastern Poland

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Key words: facies, stratigraphy, ammonites, correlation, tectonics, climate changes.

Abstract. This study discusses the development of sedimentation in the Late Jurassic on the northern margin of the huge shallow-water carbonate platform ranging through north-eastern Poland from the south-east, where it passes into the siliciclastic deposits of the foreland in the Peri-Baltic Syneclise. It is based on archival material from deep-boreholes, including the ammonites collected whose palaeontological classification and stratigraphical interpretation have been partly revised. The main stages of sedimentary development recognized include: the local appearance of shallow-water deposits during the Late Oxfordian, the foundation of the shallow-water carbonate platform during the Early Kimmeridgian, the tectonic disintegration of the platform and its drowning during the late Early Kimmeridgian to Early Tithonian, and the re-appearance of the shallow-water carbonate platform at the beginning of the Late Tithonian. These phenomena are compared with the stages of development of the coeval well-known successions including the shallow-water carbonate platform deposits in other areas in Poland (Holy Cross Mts.) and elsewhere (Jura Mts., northern Switzerland) to find features in common which could have been controlled by wider climatic and tectonic factors.

INTRODUCTION

The huge Late Jurassic shallow-water carbonate platform ranging from south-eastern Poland (Lublin area and Holy Cross Mountains) towards the north stretched generally along the East European Craton and its western foreland, and reached areas of the Mazury-Suwałki Elevation (Belarus Anteclise) near the boundary with the Peri-Baltic Syneclise in north-eastern Poland. The latter area represents already its direct foreland of siliciclastic sedimentation (Fig. 1). The aim of the study is to recognize the general history of Late Jurassic sedimentation on the northern margin of the platform from the appearance here of the first shallow-water deposits during the Late Oxfordian, the following growth of the shallow-water carbonate platform during the Early Kimmeridgian, its successive drowning at the end of the Early Kimmeridgian/beginning of the Late Kimmeridgian to the Early Tithonian, and to the re-appearance of the platform at the beginning of the Late Tithonian. The latest Tithonian-Early Cretaceous development of the platform is, however, beyond the scope of this study. The successive stages of the sedimentary development of the platform in the discussed area are documented biostratigraphically and are compared with those established in the south, in the area of the Holy Cross Mountains, but also in one of the best known areas in Europe the Late Jurassic carbonate platform of the Jura Mountains, to distinguish the main features in common of sedimentation of the Upper Jurassic deposits, and to establish their relation to tectonically and climatically-controlled wider phenomena. The comparison with deposits

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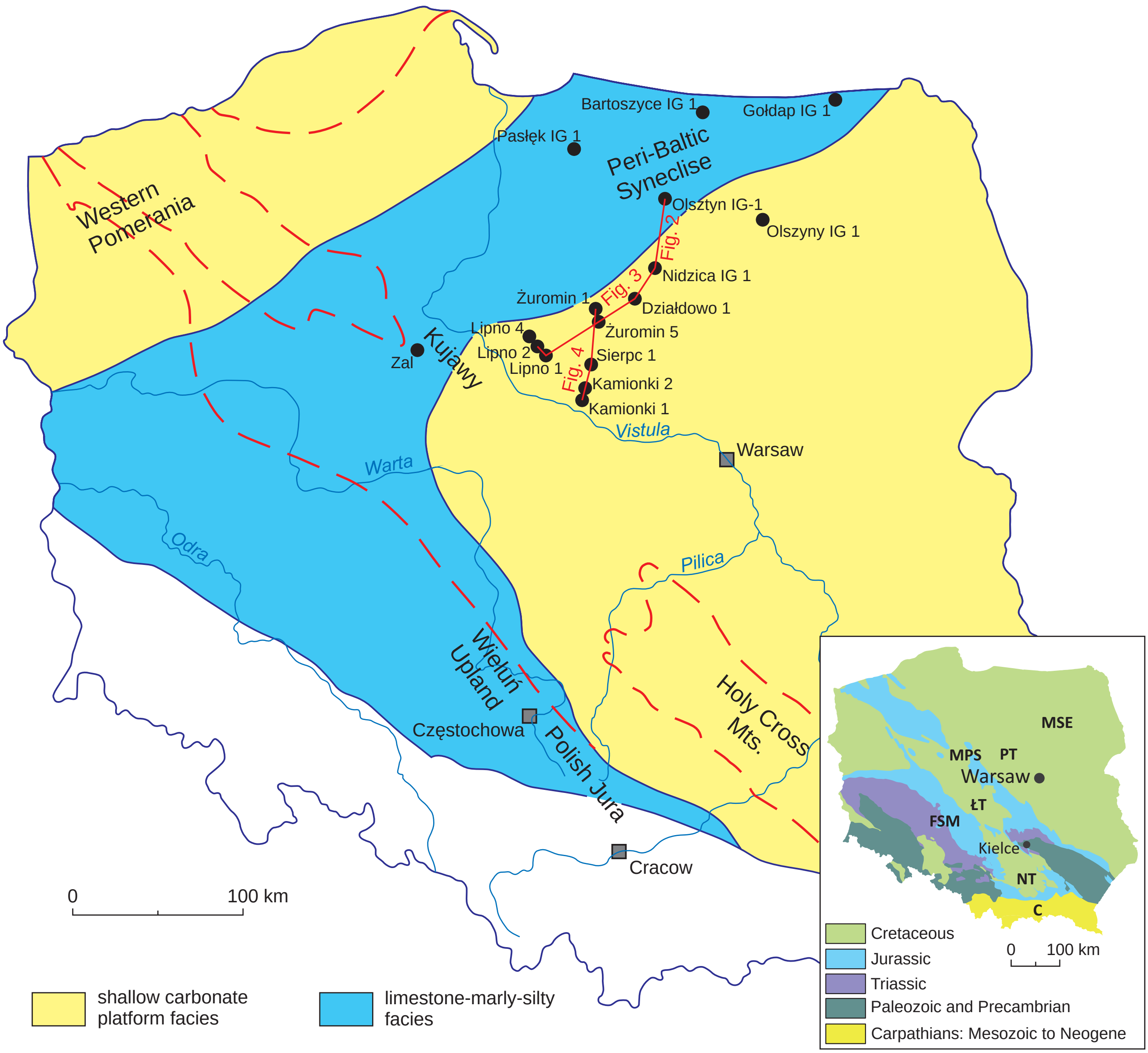


Fig. 1. Palaeogeographical map of the late Early Kimmeridgian in Poland showing the distribution of the shallow-water carbonate platform deposits (after Matyja in: Matyja, Wierzbowski, 2006)

The studied boreholes, and the sections presented in Figures 2–4 are indicated; Zal – Zalesie Anticline (qurries at Barcin). Hatched red lines show the present distribution of the deposits. Inset shows the main Laramian structures: MPS – Mid-Polish Swell, PT – Płock Trough, MSE – Mazury–Suwałki Elevation, ŁT – Łodź Trough, NT – Nida Trough, FSM – Fore-Sudetic Monocline. Other abbreviations: C – Carpathians

of another shallow-water carbonate platform in Poland in Western Pomerania is not considered herein: these deposits known from boreholes and quarries that no longer exist (Wilczyński, 1962 and older papers cited therein), reveal many features in common with the succession studied herein both in sedimentary development and in faunal characteristics, but they need careful stratigraphical revision.

GEOLOGICAL SETTING

The Upper Jurassic deposits which represent the marginal zone of the shallow-water carbonate platform are recognized in boreholes in the central part of the north-eastern limb of the Laramian Płock Trough (former known as the Warsaw Trough or Synclinorium; see *e.g.*, Dadlez, Marek, 1983; Narkiewicz, Dadlez, 2008) and the adjoining south-western slope of the Mazury-Suwałki Elevation (*e.g.*, Dembowska, 1970, 1983). The Płock Trough was formed at the end of the Cretaceous (Maastrichtian), and beginning of the Paleocene (Danian) as a middle part of the Marginal Trough developed along the eastern side of the Mid-Polish Swell (Mid-Polish Anticlinorium) which was elevated at that time. The Płock Trough is situated at the boundary of the two megatectonic units: the Pre-Vendian Platform of Eastern Europe, and the Paleozoic Platform of Central and Western Europe, with the boundary placed at the deep-founded Teisseyre-Tornquist Zone. As a whole the Płock Trough has an asymmetric structure showing a distinct south-western limb in common with the Kujavian Swell representing the middle part of the Mid-Polish Swell, and a gently sloping indistinct north-eastern limb transitional to the Mazury–Podlasie Monocline of the Mazury Suwałki Elevation (*e.g.*, Marek, Znosko, 1983).

The wide areas which actually belong to a central part of the north-eastern limb of the Płock Trough (Warsaw Trough), distinguished as the Płońsk tectonic unit, representing the south-western prolongation of the Mazury–Suwałki Elevation, suffered very intensive tectonic deformation during the Early Permian. This resulted in strong erosion of the Paleozoic deposits on elevated parts leading even to exposure of the crystalline basement in the east. The strong tectonic differentiation of the substrate of the Płońsk unit resulted possibly in its larger mobility during the Mesozoic. The Late Jurassic shallow-water deposits covered here a strongly deformed tectonic zone, and ranged up towards the north-west to the boundary with another "more quiet" tectonic zone, including the Brodnica unit and/or the Dobrzyń unit, showing nearly latitudinal orientation of its southern border (Dadlez, 1982; Dadlez, Marek, 1983; Pożaryski *et al*., 1983). This transitional area alone belongs already to the stable and weakly deformed part of the East European Platform, joining with the Mazury–Suwałki Elevation and the Peri-Baltic Syneclise. It was active during the Permo-Mesozoic when it corresponded to the northern edge of the Late Jurassic shallow-water carbonate platform developed at the contact with the siliciclastic deposits of the foreland (*cf*. Niemczycka, 1997, figs. 78, 94). The area discussed generally comprises a fragment of the major Poznań–Toruń transversal fault zone cutting through the Mid-Polish Swell and its margins during the Permo-Mesozoic (Dadlez, 1997). The zone of its nearly straight WSW–ENE trending line in its eastern prolongation, bounds the Peri-Baltic Syneclise to the Mazury–Suwałki Elevation (Wierzbowski *et al*., 2015).

MATERIALS AND METHODOLOGY

The numerous boreholes which penetrated the Upper Jurassic succession in the marginal zone of the shallow-water carbonate platform deposits include the fully-cored Nidzica IG 1 located on the Mazury–Suwałki Elevation, the lithology and stratigraphy of which has been revised recently (Wierzbowski H., Wierzbowski A., in press), and the Olszyny IG 1 borehole in the east. This study includes also several other partly cored boreholes placed generally in the adjoining part of the the Płock Trough, including those at Działdowo (Działdowo 1), and Żuromin (Działdowo 2, Żuromin 1, and Żuromin 5), and at Lipno (Lipno 1, Lipno 2, and Lipno 4), as well as, for comparison, more southward-located boreholes: Sierpc 1, Kamionki 1 and Kamionki 2. All the discussed boreholes are located approximately along the NE–SW line lying between the Płońsk and Dobrzyń/Brodnica tectonic units of the Płock Trough. Thus they are also situated across the structural transition from the Mazury–Suwałki Elevation towards the structural step in the Permian-Mesozoic basement corresponding already to the Teisseyre–Tornquist zone, marking the beginning of the Mid-Polish Swell. On the other hand, there are considered here boreholes located towards the north on the siliciclastic foreland of the Late Jurassic shallow-water carbonate platform in the the Peri-Baltic Syneclise: especially Olsztyn IG 1, and for comparison Gołdap IG 1, Bartoszyce IG 1 and Pasłęk IG 1. Such an approach offers the possibility of recognizing the general facies pattern as controlled by ammonite stratigraphy across the marginal zone of the platform towards its siliciclastic foreland from south to north, and along the marginal zone of the shallow-water carbonate platform from the north-east to the south-west (Fig. 1).

All the material from the boreholes has been studied and partly revised, mostly after descriptions of the cores presented in several published and unpublished statements (*e.g.*, Dembowska, 1962, 1970, 1983; Kutek *et al*., 1973; Dembowska, Malinowska, 1976, 1977; Niemczycka, 1976a, 1983; Wierzbowski *et al.*, 2015). In addition the ammonites and selected lithological samples preserved in the Museum of the Polish Geological Institute – National Research Institute have been studied and some older palaeontological determinations revised. Some comments on the revised determinations of the ammonites are given in the Appendix at the end of this study.

The lithostratigraphy of the Upper Jurassic deposits is generally based on the proposal of Dembowska (1979) who recognized eight main formations for the area of north-eastern and central Poland: the sponge-limestone formation (I), the limestone-marly formation (II), the coral formation (III), the oolitic formation (IV), the limestone-marly-coquina formation (V), the shale-marly-siltstone formation (VI = Pałuki Formation), and limestone-evaporatic formation (VII = Kcynia Formation), as well as the siltstone formation (VIII = Łyna Formation). It should be remembered, however, that recognition of the coral formation (III), as originally proposed for the coral reef deposits developed over the sponge limestones (Dembowska, 1979), is often difficult when interpreting older descriptions of the core sections. The deposits containing coral buildups and associated bedded coral limestones have been commonly confused in the past with the "chalky limestones", soft, bedded limestones containing various carbonate grains (especially oncoids), associated sometimes with oolitic limestones, and containing abundant fossils, such as hermatypic corals, solenoporoids, bivalves (diceratids and oysters) and nerineid gastropods. The "chalky" limestones commonly occur in the lower part of the oolitic formation (IV) of Dembowska (1979), as well as in the partly corresponding coral-oolitic formation as proposed by Kutek *et al.* (1973) in the Płock (Warsaw) Trough. These deposits are recognized herein as the lower part of the oolitic formation (marked as unit IVa, possibly to be distinguished in the future at formation rank), directly below its upper part (IVb), composed to large degree of oolites. Additionally, a new lithostratigraphic unit – the Nidzica Member corresponding to the limestone-marly-coquina formation (V) has been formally distinguished, and its description is presented in the Appendix.

The chronostratigraphical subdivision of the Upper Jurassic deposits in the Płock (Warsaw) Trough area has remained for a long time strongly under the influence of the formerly recognized "stages" such as the "Argovian", "Rauracian" and "Astartian", this being in fact the lithostratigraphical subdivision partly because of the scarcity of ammonites, and also because of the lithostratigraphical definition of the units (*cf*. *e.g*., Kutek *et al*., 1973). These "stages", however, were correlated subsequently, on very general assumptions, with the chronostratigraphical scale: originally (*e.g*., Dembowska, 1970), with the Middle Oxfordian, as well as the lower part, and the upper part of the Upper Oxfordian, respectively, but later (*e.g*., Niemczycka, 1976a), the deposits previously recognized as belonging to the "Argovian" and "Rauracian" were correlated with the Middle Oxfordian, and those of the "Astartian" – with the Upper Oxfordian. Detailed stratigraphical and palaeontological study of the Upper Jurassic shallow-water deposits including the intervening deeper-water deposits of the Mesozoic margins of the Holy Cross Mountains in central Poland, as recently recognized (Wierzbowski, 2023; but see also older stratigraphically important papers, *e.g.*, Kutek, 1968; Matyja, 1977; Gutowski, 1998; Matyja, Wierzbowski, 2014) has enabled the chronostratigraphical subdivision of the summarized local lithological columns, which has given the basis for wider stratigraphical correlations. It is worth mentioning that the recent modification of the Oxfordian/Kimmeridgian boundary in Submediterranean Europe (Wierzbowski *et al*., 2023), including areas of northern and central Poland, changed markedly the chronostratigraphical position of the Oxfordian and Kimmeridgian boundary in the here accepted ammonite zonal scheme, down to the base of the Bimammatum Chronozone. Moreover, the deposits correlated with the Upper Kimmeridgian, and those attributed previously, depending on the subdivision accepted, to the "Portlandian" or "Volgian" (see Dembowska, 1973; Kutek *et al*., 1973), containing abundant ammonites, can be easily correlated with the nowadays distinguished Upper Kimmeridgian, and the Tithonian (including the possibility of recognition of the Lower and the Upper Tithonian substages, see Matyja, Wierzbowski, 2016; Błażejowski *et al*., 2023). The ammonite zones of the Submediterranean, Subboreal and Boreal subdivisions and their correlation, crucial for the stratigraphic interval from the Upper Oxfordian to the Lower Tithonian in northern Poland, are presented in Table 1. The Upper Oxfordian to Lower Kimmeridgian interval shows a wide applicability here of the Submediterranean, Boreal and NW European Subboreal zonations (*e.g.,* Wierzbowski *et al.*, 2015), the Upper Kimmeridgian shows applicability of the Subboreal and Boreal zonations, whereas from the top of the Kimmeridgian and through the whole Lower Tithonian ("Lower to lowermost Middle Volgian") the NE European Subboreal zonation can be applied (*e.g.,* Kutek, Zeiss, 1997).

The development of sedimentation during the Late Jurassic in epicratonic areas of Poland was controlled by tectonics (*e.g.*, Kutek, 1994a) and climate changes, especially well recognizable in shallow-water carbonate deposits (*e.g.*, Wierzbowski, 2023). All the major variations in the character of the deposits, including their transgressive or regressive character, were the net-result of changes of sea-level mostly controlled by orbitally-climatic cycles and tectonic activity along the deeply-founded fault zones. The evidences for orbitally-controlled 100-kyr and 405-kyr eccentricity cycles, well-recognized in the Lower Kimmeridgian deposits of south-eastern France where there is good ammonite documentation (Atrops, 1982; Boulila *et al.*, 2008, 2010), has been demonstrated in the lithological succession of central Poland (Wierzbowski, 2017, 2020, 2023, 2024). Additionally, some long-time climatic changes from arid to humid intervals, ranging to about 2.4 myr for a full cycle, have been also recognized (Grabowski *et al.*, 2021). Comparison of the succession studied in north-eastern Poland with that of the marginal areas of the Holy Cross Mts. area well dated by ammonite faunas, makes possible subdivision of these Upper Jurassic deposits according to the climatically and tectonically controlled phenomena, thus giving an additional support for a more general consideration of the history of sedimentation of the whole carbonate platform area. The biostratigraphy and lithostratigraphy of the succession studied have been compared also with those of the Jura Mountains, northern Switzerland, representing one of the best

Table 1

The ammonite zonal schemes of the studied stratigraphical succession of the Upper Oxfordian to the Lower Tithonian in northern Poland (the chronostratigraphical scale is given after Hesselbo *et al.*, 2020)

Stage	Substage	MA	Submediterranean	Subboreal NW European	Subboreal NE European	Boreal
Tithonian	Upper	12	zones not recognizable	Albani	Virgatus	zones not recognizable
	Lower			Fittoni		
		11		zones not recognizable	Scythicus	
		10			Tenuicostata	
					Pseudoscythica	
		9			Sokolovi	
					Klimovi	
Kimmeridgian	Upper	8		Autissiodorensis	Fallax	
					Subborealis	Nannocardioceras
		7		Eudoxus	Caletanum	Elegans
		6	Acanthicum	Mutabilis	Schilleri	Kochi
			Uhlandi		Askepta	
	Lower		Divisum	Cymodoce		Kitchini
		5	Hypselocyclum			
			Platynota			Bayi
		4	Planula	Baylei	Normandiana	Bauhini
		3	Bimammatum		Densicostata	
Oxfordian	Upper	2	Hypselum	Pseudocordata		Rosenkrantzi
		1	Bifurcatus			Regulare
						Serratum
			Wartae	Cautisnigrae		Glosense
	Middle	0	Transversarium			Tenuiserratum

known Late Jurassic carbonate platform successions in Europe (*e.g.*, Gygi *et al.*, 1998; Gygi, 2000; Jank *et al.*, 2006a, b; Comment *et al.*, 2015), to decipher the main features in the history of sedimentation – with features of both climatic and tectonic natures influencing the depositional environment.

FACIES AND STRATIGRAPHY

FROM THE MAZURY–SUWAŁKI ELEVATION TO THE PERI-BALTIC SYNECLISE: ACROSS THE MARGINAL ZONE OF THE PLATFORM TOWARDS ITS SILICICLASTIC FORELAND

Most important for the recognition of the Upper Jurassic succession of this area is the fully-cored Nidzica IG 1 borehole. The lithological and stratigraphical interpretation of the cored section (Dembowska, 1962; Wierzbowski H., Wierzbowski A., in press; Fig. 2) indicates that the lowest deposits attaining 66.3 m in thickness (1390.3–1324 m) belong to the sponge-limestone formation (I), recognized in central Poland as the Częstochowa Sponge Limestone Formation (see Matyja, Wierzbowski, 2004). The formation begins in the core with marly limestones and marls containing abundant fauna (ammonites, belemnites, bivalves, brachiopods, sponges).These deposits, about 3 m in thickness, correspond to the Jasna Góra Limestone and Marl Member ("Jasna Góra beds") well known in the Polish Jura and the Holy Cross Mountains areas. The ammonites found in the core include: *Cardioceras* (*Scarburgiceras*) and *Cardioceras* (*Cardioceras*) below, indicative of the Lower Oxfordian (Bukowskii and Cordatum zones), attaining about 1,0–1.5 m in thickness, and occurring above *Cardioceras* (*Plasmatoceras*) indicative of the lowermost Middle Oxfordian (Densiplicatum Zone). The overlying tuberoolitic-sponge limestones with cherts corresponding to the Zawodzie Limestone Member yielded the Middle Oxfordian perisphinctid ammonites: *Perisphinctes* (*Otosphinctes*) at 1387.2 m (about 3 m above the base of the Upper Jurassic, well known in the Plicatilis Zone), and *Perisphinctes* (*Dichotomosphinctes*) at 1367.0 m and 1360.8 m (23.3 m and 29.5 m above the base of the Upper Jurassic, respectively, indicative of the Transversarium Zone). The total range of the Middle Oxfordian deposits cannot be estimated precisely in the core, but possibly it does not markedly exceed about 30 m in thickness. This strongly suggests that the upper part of the sponge limestone formation (*i.e*. Częstochowa Sponge Limestone Formation) in the core belongs already to some lower parts the Upper Oxfordian. The specific change in character of the deposits and in the ammonite faunas recognized here are akin to those recognized in the Oxfordian in central Poland: the lowermost more marly part of the Middle Oxfordian, similarly as the underlying Lower Oxfordian deposits, reveals commonly Boreal cardiocertids, and the upper part, rich in limestones, yields Mediterranean-Submediterranean perisphinctids. This is interpreted as the consequence of climate and sea-water circulation change – from the cardioceratid-dominated so-called "Boreal spread" to the "Mediterranean spread" (see Głowniak, 2002; Dembicz *et al.*, 2006).

The directly overlying deposits in the Nidzica IG 1 borehole at 1324.0–1194.2 m are limestones with hermatypic corals associated with a facies-dependent fauna consisting predominantly of sponges, brachiopods (including *Septaliphoria astieriana* (d'Orb.), bivalves (*Plicatula*, *Ctenostreon*, *Modiolus*, *Lopha*) and echinoids (Dembowska, 1962). Some subordinate marly intercalations are seen (1244.5–1243.2 m, 1280.4–1273.9 m). These deposits attaining nearly 130 m in thickness belong to the coral formation (III), which should be formally established in future basing on the sections from the north-eastern margin of the Holy Cross Mts., especially of the Bałtów area (*cf.* Dembowska, 1979). The chronostratigraphical position of these deposits, because of the scarcity of ammonites in the cores in north-eastern Poland, has been highly disputable. The deposits were originally referred to the "Rauracian", mostly because of the occurrence of the brachiopod *Septaliphoria astieriana* (see *e.g.*, Dembowska, 1962), and correlated later either with the Middle Oxfordian or with the Upper Oxfordian (*e.g.*, Niemczycka, 1976a, 1997; Malinowska, 1997). It is worth noting, however, that the brachiopod *S. astieriana* is in fact a facies-dependent fossil occurring in the coralline and coralline-sponge limestones, and it has been recorded already in the Bifurcatus Zone of the Upper Oxfordian in the north-eastern margin of the Holy Cross Mountains (*e.g.*, Liszkowski, 1976), and it has appeared much higher stratigraphically in the upper Planula to Platynota zones of the lowermost Kimmeridgian in the Wieluń Upland, according to distribution of the facies in question (Wierzbowski, 1970). The only ammonite found in the coral formation in the Nidzica IG 1 borehole at 1260 m (and the only one found in these deposits in north-eastern Poland: illustrated as "*Ringsteadia* sp" *in*: Malinowska, 1991, pl. 11: 21) is an aulacostephanid of the genus *Vineta*, referred herein (Pl. 1: 1) to as *Vineta* cf. *submediteranea* (Wierzbowski). It is indicative already of the lowermost Kimmeridgian – being known from the Bimammatum Zone (Wierzbowski *et al.*, 2010) to the Planula Zone (Wierzbowski, 2022). It occurrence indicates that the upper part of the coral formation belongs to the lowermost Kimmeridgian. The problem of the approximate location of the Oxfordian/Kimmeridgian boundary in the core studied needs, however, additional discussion.

Some information on the position of the Oxfordian/Kimmeridgian boundary can be obtained from analysis of

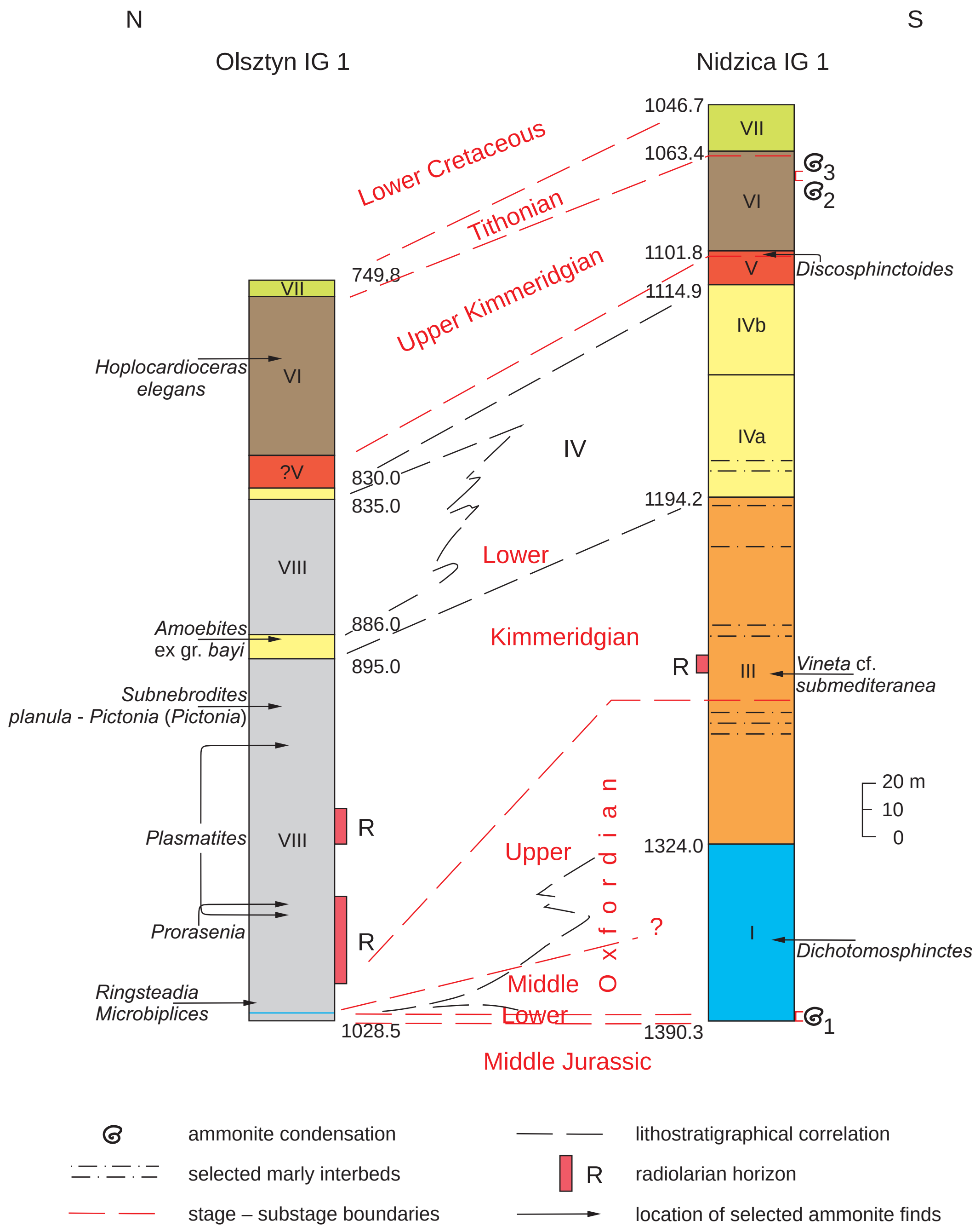


Fig. 2. Lithostratigraphical and chronostratigraphical correlation of the Upper Jurassic deposits between the area of the shallow-water carbonate platform (borehole Nidzica IG 1, after Dembowska, 1962; Wierzbowski H., Wierzbowski A., in press), and its siliciclastic foreland (borehole Olsztyn IG 1, after Dembowska, 1977; Dembowska, Malinowska, 1976, 1977; markedly modified)

Numerical explanations of the formations (after Dembowska, 1979) are as follows: I – sponge limestone formation (Częstochowa Sponge Limestone Formation); III – coral formation; IV – oolitic formation (IVa – chalky limestone unit; IVb – oolitic limestone unit, as recognized herein); V – limestone-marly-coquina formation (Nidzica Member as proposed herein); VI – shale-marly-siltstone formation (Pałuki Formation); VII – limestone-evaporatic formation (Kcynia Formation); VIII – siltstone formation (Łyna Formation). The most important ammonite occurrences from the Middle Oxfordian to the Kimmeridgian are indicated in the figure. The separately distinguished ammonite condensations are as follows: (1) *Cardioceras* (*Scarburgiceras*) to *C.* (*Cardioceras*) below, and *C.* (*Plasmatoceras*) above, Nidzica IG 1: 1390.3–1387.7 m (Lower to lowermost Middle Oxfordian); (2) *Sarmatisphinctes subborealis* followed by *S. fallax* and *Aulacostephanus*, Nidzica IG 1: 1067.5–1066.0 m (uppermost Upper Kimmeridgian); (3) *Ilowaiskya klimovi* followed by *I. pseudoscythica* and *I. tenuicostata – Zaraiskites quenstedti*, and *Z. scythicus* above, Nidzica IG 1: 1065.6–1063.5 m (Lower Tithonian). Location of the section is shown in Figure 1 the Olsztyn IG 1 borehole (Fig. 2), located about 50 km to the north of the Nidzica IG 1 borehole. The Oxfordian and the Lower Kimmeridgian in the Olsztyn IG 1 section are developed in the marly to silty facies representing the Łyna Formation (VIII) typical of the Upper Jurassic of the Peri-Baltic Syneclise (Dembowska, 1979). The lithological development of the lower part of the succession (unfortunately not cored) suggests the presence of a very thin (1028.5–1026.0 m), about 2.5 m in thickness, interval of silty to marly deposits corresponding to the Lower Oxfordian, which is followed by a thin packet of limestones (1026–1024 m) possibly corresponding to the Middle Oxfordian (Dembowska, 1977; Dembowska, Malinowska, 1977). The overlying fully-cored deposits (1024–1018 m) are marly silts which yielded abundant ammonites mostly of the genus *Amoeboceras* indicative of the Upper Oxfordian (Malinowska, 1991). The youngest of the specimens are: *Amoeboceras ovale* (Quenstedt) from 1018.7 m, described as "*A. serratum* (Sowerby)" by Malinowska (1991, pl. 5: 25), and *A. leucum* Spath from 1018.7–1019.2 m, described as "*A. lorioli* (Oppenheimer)" by Malinowska (1991, pl. 5: 7, 9, 10), both indicative of the Boreal Rosenkranzti Zone of the uppermost Oxfordian. Additionally, some specimens identified in the collection by the present author include: *Ringsteadia* sp. at 1021.7 m and *Microbiplices* sp. at 1021.1 m and 1018.6 m of the Pseudocordata Zone of the uppermost Subboreal Oxfordian. Unfortunatelly, the following interval (1018–988 m) was not cored, but the ammonite occurring directly above, from 987.3 m, originally described to as "*Amoeboceras* sp." (Malinowska, 1991, pl. 5: 12), is *Plasmatites* indicative already of the Boreal Bauhini Zone of the lowest Kimmeridgian. Similarly identified by the present author specimens of *Prorasenia* cf. *bathyschista* (Koerner) at 986.5, 985.7 and 982.2 m in the collection (Pl. 1: 2, 3) are also indicative of the Lower Kimmeridgian. These ammonites come from a more calcareous stratigraphical interval in the core (described as "calcareous silty marls"), which is sandwiched in between more silty deposits of the Upper Oxfordian below, and a unit of similar lithology above (945.5–938.7 m) (see Dembowska, 1977), the latter belonging to the lowermost Kimmeridgian. The microfossil analysis of the bailer samples taken from 1015–988 m, and from 957.5 m, all in the non-cored interval, and additionally of the core sample from 947.5 m, revealed the mass-occurrence of radiolarians (Bielecka, 1977: description, and fig. 9; but note that the intervening cored interval 988–982 m was not sampled). This is the radiolarian horizon which occurs at the base of the Kimmeridgian, in the Bauhini Zone, in the Peri-Baltic Syneclise (Smoleń *et al.*, 2014; Wierzbowski *et al.*, 2015).

The proposed correlation between the Nidzica IG 1 section and the Olsztyn IG 1 section takes into account the recognized ammonites, and the occurrence of more and less calcareous deposits as follows: the limestone unit (1273.9–1244.5 m) which yielded the ammonite of the genus *Vineta* (at 1260 m) in the Nidzica IG 1 borehole can be correlated with a more calcareous interval of silty marls and marls of the lowermost Kimmeridgian in the Olsztyn IG 1 borehole (1018.0–945.5 m), whereas both of the marly intervals in the Nidzica IG 1, below and above the limestone unit (1280.4–1273.9 m, and 1244.5–1243.2 m) can be correlated possibly with the marly silts of the Upper Oxfordian, and of the lowermost Kimmeridgian in the Olsztyn IG 1 borehole, respectively. It is worth noting that a lithologically similar sequence of deposits around the Oxfordian/Kimmeridgian boundary was reported from the Kcynia IG 4 borehole section, very precisely dated by ammonites (Matyja, Wierzbowski, 1998), and, although placed markedly westwards, represents the same zone of occurrence of the Łyna Formation. Additionally, the analysis of thin-sections from the Nidzica IG 1 borehole by the author revealed the presence at 1260.5–1257.7 m of micritic limestones showing the abundance of rounded heavily recrystallized spherical microforms, possibly representing radiolarians. These come from the intercalation of micritic limestones within the coral formation, directly below the ammonite find. All these data firmly locate the Oxfordian/Kimmeridgian boundary in the Nidzica IG 1 section in the limestone unit, generally in between 1260 m (location of the Lower Kimmeridgian ammonite) and 1273.9 m (occurrence of marly unit possibly correlated already with the Upper Oxfordian). In consequence, the Oxfordian/Kimmeridgian boundary can be placed around 1270 m, and the Oxfordian deposits in the core can be estimated at about 120 m in thickness.

A very similar succession to that of the Nidzica IG 1 is shown in the Olszyny IG 1 borehole located about 50 km towards the east. The total thickness of the sponge-limestone formation and the coral formation as recognized in the Olszyny IG 1 borehole (Niemczycka, 1976a, fig. 64) is comparable to that of the Nidzica IG 1 borehole (176 m *versus* 196 m) but recognition of the detailed boundary is difficult. The detailed sketch of the distribution of the faunal remains in the Olszyny succession (Dembowska, Malinowska, 1976, fig. 70) suggests, however, that the coralliferous facies is somewhat less thickly developed here which may indicate that the Oxfordian/Kimmeridgian runs somewhat lower in the coral formation when compared with the Nidzica IG 1 section.

The higher lithostratigraphical unit in the Nidzica IG 1 core section consists of deposits correlated with the oolitic formation (IV) of Dembowska (1979). These are generally represented by shallow-water carbonates attaining about 80 m in thickness (1194.2–1114.9 m). The two subunits are informally separated on the basis of a rather sharp faunal and lithological change. The lower one (IVa) up to about 1140–1150 m is dominated by whitish, soft, porous, "chalky" limestones having an extremely prolific fossil assemblage (see Dembowska, 1962): *Solenopora* algae, corals, gastropods of the family Nerineidae (*Nerinea*, *Ptygmatis*), various bivalves (*Diceras*, *Trigonia*, *Isognomon*, *Astarte*, *Pholadomya*, ostreids), brachiopods (*Septaliphoria*, *Zeilleria*) and echinoids; additionally, some oncolitic limestone beds are also seen. The intercalations of silty clays, locally with plant debris, are recorded in the lowermost part of the subunit, but also in the topmost part of the underlying coral formation (from about 1200 m to about 1181 m): these are generally of small thickness (0.1–0.2 m), but a more prominent bed of silty marls, about 1.3 m in thickness was recorded at the top (1182.3–1181.0 m). Additionally, a few thin interbeds of grey siltstones are seen also higher at about 1155–1156 m. The higher subunit (IVb), from about 1140–1150 m up to the top of the formation displays the domination of oolitic limestones which are associated with micritic limestones. The fauna has become more monotonous being represented mostly by bivalves (*Astarte*, *Trigonia*, *Lucina*, *Corbis*), brachiopods (*Septaliphoria*, *Zeilleria*), and echinoid spines (Dembowska, 1962).

The oolitic formation in the Nidzica IG 1 borehole section was originally (*e.g.*, Dembowska, 1962) attributed to the "Astartian" stage, which has been correlated later, either with the upper part of the Upper Oxfordian (*e.g.*, Dembowska, 1970), or even with the whole Upper Oxfordian (*e.g.*, Niemczycka, 1976a). The stratigraphical classification of the oolitic formation has not been straightforward, however, because the deposits in the area did not yield any ammonites. The age of similar deposits in the adjoining areas of Kujawy (*e.g.*, Marek, 1961; Karczewski, 1961) was based on the stratigraphical ranges of the facies-dependent fossils: gastropods, bivalves, brachiopods and others, and thus remained highly imprecise. Hence, the chronostratigraphical interpretation of the oolitic formation as discussed herein is based on its stratigraphical correlation with similar deposits well dated by ammonites in the Holy Cross Mountains, and the Wieluń Upland. The deposits discussed in the Nidzica IG 1 section show marked lithological similarity in their lower part to the "chalky" limestones and micritic limestones of the Bukowa Formation in the south-western margin of the Holy Cross Mts., and partly also to the Prusicko Formation in the Wieluń Upland, the zonal position of which has been established on the basis of ammonites as corresponding mostly to the Lower Kimmeridgian Platynota Zone (Wierzbowski, 2017, 2020). It is worth noting moreover that the characteristic marly to marly-silty unit distinguished as the Latosówka Marl Member occurring at the base of these two formations, correlates with the uppermost part of the Planula Zone, directly below the lowermost Platynota Zone. The member is of a marked stratigraphical importance because its origin resulted from tectonic activity but also superimposed climatic factors (Wierzbowski, 2017, 2023). Thus, the suggested close correlation between argillaceous deposits of the lowermost part of the oolitic formation in the Nidzica IG 1 section and the discussed member strongly supports the age constraints of the directly overlying "chalky" limestones in the core, additionally confirming their correlation with the Platynota Zone. On the other hand, the upper part of the oolitic formation in the Nidzica IG 1 core section, rich in oolitic limestones, can be easily correlated with similar oolitic units in the Holy Cross Mts., such as the Małogoszcz Oolite Formation corresponding to the upper part of the Platynota Zone, and the lowermost part of the Hypselocyclum Zone (see Wierzbowski, 2020, 2023).

The occurrence of some marker beds in the rather monotonous Lower Kimmeridgian succession of marly siltstones, marls and clays of the Łyna Formation in the Olsztyn IG 1 borehole (Fig. 2), along with some ammonites discovered in the section, is also of correlation value, and gives some further evidence making possible the interpretation of the chronostratigraphical position of the oolitic formation in the Nidzica IG 1 borehole. These marker beds include: (1) redeposited oncoids at 895–886 m in silty marlstones, (2) redeposited ooids and intraclasts of micritic and oolitic limestones at 835–830 m in oolitic limestones with glauconite showing marly to clayey intercalations (Radlicz, 1977, see also Dembowska, 1977). It should be remembered additionally, that the cardioceratid ammonite described as "*Amoeboceras lineatum* (Quenstedt)" by Malinowska (1991, pl. 10: 14) from 885.9 m in the Olsztyn IG 1 borehole (*i.e.* coming from the lower marker bed) represents a very-densely ribbed form transitional to the genus *Amoebites* of the *A. bayi* group: it is known from the lowermost part of Boreal Kitchini Zone of the Lower Kimmeridgian (and the corresponding lower part of the Platynota Zone, *cf.* Atrops *et al.*, 1993). Other ammonites in the Olsztyn IG 1 section include: *Plasmatites* sp. at 987.3 m (as reported above), *Plasmatites praebauhini* (Salfeld) from 932.8 m ("*Amoeboceras* sp. F" *in*: Malinowska, 1991, pl. 8: 12), and *Plasmatites* sp. at 924.8 m ("*Amoeboceras* sp. ex gr. *schulginae* Mesezhnikov" *in*: Malinowska, 1991, pl. 8: 10), all of them indicative of the Bauhini Zone of the lowermost Kimmeridgian, and showing a very wide range of this zone in the section. Additionally, there have been described: *Vielunia flexuoides* (Quenstedt) (as "*Ringsteadia weinlandi*" *in*: Malinowska, 1991, pl. 8: 15) from 935.6 m, and some *Metahaploceras* possibly corresponding to *M. litocerum* (Oppel) (as "*Taramelliceras pseudowenzeli*" and "*T. wenzeli" in*: Malinowska, 1991, pl. 11: 14, 15) from 923.1, and 909.7 m. These are indicative of the upper Bimammatum to Planula zones of the Submediterranean zonal scheme which interval correlates well with the Boreal Bauhini Zone (*e.g.*, Wierzbowski *et al.*, 2010; Wierzbowski, 2022). This correlation actually finds its spectacular confirmation in the discovery in the collection of a single specimen of *Subnebrodites planula* (Hehl in Zieten) – *S. laxevolutum* (Font.) at 909.3 m (Pl. 1: 5) diagnostic of the middle part of the Submediterranean Planula Zone, which co-occurs with *Pictonia* (*Pictonia*) aff. *normandiana* Tornquist at 909.5 m (Pl. 1: 4) indicative of the upper part of the Subboreal Baylei Zone (see Matyja *et al.*, 2006b; see also Appendix). These correlations suggest additionally that the marker beds discussed above in the Olsztyn IG 1 borehole are directly younger than the Bauhini-Planula time-interval, and because they contain redeposited material from the shallow-water deposits (*cf*. Radlicz, 1977), that the onset of sedimentation of the oolitic formation occurred during the Platynota Chron.

The limestone-marly-coquina formation (V) in the Nidzica IG 1 borehole shows an unusual development. It consists of oolitic limestones and organodetrital limestones with glauconite grains overlain by fine-grained sandstones and siltstones with thin intercalations of fine-grained bivalve coquina and *Nanogyra* shells; grey clays with a very poor fauna are recorded only in the lowermost part of the succession. As a whole the deposits attain only 13.1 m in thickness, including the underlying clay unit 3.5 m thick (Dembowska, 1962). These deposits showing unique lithological development were compared previously with some reservation to the Raducz (Raduckie) Member distinguished by Dembowska (1979, 1986) after the Raducz IG 1 borehole in southern part of the Płock Trough; however, they differ markedly in their very small thickness, the common occurrence of siltstones and sandstones with glauconite, and generally in subordinately encountered coquina intercalations, and deserve actually to be distinguished into a separate lithostratigraphical unit – the new name proposed herein is the Nidzica Member (see Appendix, see also comments below in the description of the Płock Trough). They are replaced laterally towards the west and south by marly deposits with interbeds of *Nanogyra* coquinas, representing the typical deposits of the limestone-marly-coquina formation, and attaining even 100–300 meters in thickness (Dembowska, 1979). The corresponding deposits of the coquina formation in the south-western and north-western margins of the Holy Cross Mountains, but partly preserved due to the Early Cretaceous erosion, are from 110 to more than 200 meters in thickness, and have been referred to as the Coquina Formation or the Stobnica Coquina Formation (Kutek, 1968, 1994a; Matyja *et al*., 2006a; Matyja, Wierzbowski, 2014).

The chronostratigraphical interpretation of the discussed deposits of the limestone-marly-coquina formation needs some discussion. These deposits in the Płock Trough and adjoining areas were correlated usually in the past with the whole Lower Kimmeridgian (*e.g*., Dembowska, 1970, 1983; Niemczycka, 1976a). It should be remembered, however, that an unusual development of these deposits in some sections, including the Nidzica IG 1 borehole showing commonly some features of intermittent sedimentation (like sedimentary discontinuities, and synsedimentary erosion) along with occurrence of the Late Kimmeridgian deposits well dated by ammonites directly above, have been considered to suggest even a wider stratigraphical range of these deposits here – from the Lower Kimmeridgian and up to some lowermost part of the Upper Kimmeridgian (Dembowska, 1962). The ammonites recognized in similar deposits in some other boreholes in the Płock Trough, like Żuromin 1, Żuromin 5, Sierpc 1 (*e.g*., Niemczycka, 1983, but revised partly herein – see Appendix, see also below) are generally indicative mostly of the upper part of the Lower Kimmeridgian (the Hypselocyclum Zone, and the Divisum Zone), and possibly some lower parts of the Upper Kimmeridgian. This correlates well with the lower part of the Coquina Formation in the Holy Cross Mountains which is well dated by ammonites (*e.g*., Kutek, 1968; Wierzbowski, 2024). The whole succession of deposits corresponding to the Coquina Formation in south-eastern Poland has been treated as representing the well-defined tectono-stratigraphic unit called the LUK (Lower-Upper Kimmeridgian) transgressive-regressive sequence (Kutek, 1994a). It ranges stratigraphically from the uppermost part of the Lower Kimmeridgian to some lower parts of the Eudoxus Zone of the Upper Kimmeridgian (*e.g*., Kutek, 1994a; Wierzbowski, 2023).

The shale-marly-siltstone formation (VI), formally recognized as the Pałuki Formation (Dembowska, 1979), attains 38.4 m in thickness in the Nidzica IG 1 borehole (1101.8–1063.4 m). The deposits are developed in predominantly silty marl facies, showing a more clayey character in their lower part, about 15 m thick (1101.8–1087.0 m). Fossils are dominated by ammonites: the lowest ammonite fauna encountered in the argillaceous deposits in a lower part of the section consists mostly of numerous small-sized cardioceratid *Nannocardioceras*, especially *N. krausei* (Salfeld), associated with some aulacostephanids (*Aulacostephanus*), ataxioceratids (*Discosphinctoides*; Pl. 1: 9), aspidoceratids (*Sutneria*) and oppeliids (*Glochiceras*). The fauna corresponds to that of the amoeboceras horizon, originally distinguished as the second ammonite faunal horizon in the succession of the Upper Kimmeridgian deposits in central and northern Poland (Dembowska, 1965). It can be correlated with some upper parts of the Eudoxus Zone up to the transition between the Eudoxus Zone and the Autissiodorensis Zone of the Upper Kimmeridgian (see Kutek, Zeiss, 1997; Wierzbowski, Wierzbowski, 2019). The occurrence of the lowest ammonite fauna (of the sub-amoeboceras horizon of Dembowska, 1965) is, however, not proven in the borehole studied, which suggests either an erosional hiatus at the base of the Pałuki Formation, or implies that the uppermost part of the underlying silty marls of the limestone-marly-coquina formation is its time equivalent.

The upper part of the Pałuki Formation in the Nidzica IG 1 core (1087.0–1063.4 m) can be subdivided on the basis of ammonites into two faunal units. The lower unit recognized at 1087–1066 m corresponds to the "virgataxioceras horizon" (Dembowska, 1965), which according to the new systematic classification of ammonites should be re-named the sarmatisphinctes horizon (*cf.* Kutek, Zeiss, 1997; Rogov, 2010). The relevant deposits of about 21 m in thickness yielded abundant ammonites (see Dembowska, 1962): oppeliids (*Glochiceras*), ataxioceratids (*Sarmatisphinctes*), aulacostephanids (*Aulacostephanus*) and aspidoceratids (*Sutneria*, *Aspidoceras*); in the lowermost part (1087–1082.4 m) some fragmentarily preserved, densely-ribbed cardioceratids occurred as well, referred to as *Nannocardioceras* cf. *volgae* (Pavlov) – these are indicative of the lower part of the Autissiodorensis Zone of the uppermost Kimmeridgian (Rogov, 2010). The ammonites of the genus *Sarmatisphinctes* belong mostly to the two species: *Sarmatisphinctes subborealis* (Kutek et Zeiss) ranging up to 1067.6 m in the core (Pl. 2: 6), and indicative of the Subborealis Subzone, and *Sarmatisphinctes fallax* (Ilovaisky) occurring at 1067.6–1066.0 m (Pl. 2: 2), and indicating the Fallax Subzone at the top of the Autissiodorensis Zone (*e.g.*, Kutek, Zeiss, 1997; Zeiss, 2003; Rogov, 2010; see also Appendix). This corresponds well to the occurrence of the last *Aulacostephanus* at 1066.6 and 1066.3 m.

The upper unit recognized at 1066.0–1063.4 m is of Tithonian age, but it shows some peculiarities in its development. The lowermost bed of 0.7 m in thickness contains fine shell debris with fragments of ammonites of the family Oppeliidae (? *Neochetoceras*). These oppeliid ammonites have been reported in central Poland in the lowermost Tithonian ("Volgian") beginning from its base (Klimovi Zone) (Kutek, Zeiss, 1997). The occurrence of *Ilowaiskya klimovi* (Ilovaisky) in the core at 1065.6 m (Pl. 3: 1) is unequivocal evidence of the Klimovi Zone, whereas the presence of *Ilowaiskya pseudoscythica* (Ilovaisky) at 1065.2 m (Pl. 3: 2, 3) indicates already the presence of the Pseudoscythica Zone of the Lower Tithonian. The overlying deposits at 1065.2–1063.4 m have also yielded ammonites which are important stratigraphically: (1) the specimens from 1064.8–1064 m represented by the inner whorls covered with single and biplicate, densely-placed ribs splitting very low on the whorl sides, which may represent either *Ilowaiskya tenuicostata* (Michailov) typical of the Tenuicostata = Puschi Zone or the earliest *Zaraiskites quenstedti* (Rouillier) of the lowermost Scythicus Zone; (2) the specimens from 1063.9–1063.5 m (Pl. 3: 4, 5) which evidently represent the genus *Zaraiskites*, and the most likely *Z. scythicus* (Vischn.), known from the Scythicus Subzone of the lower part of the Scythicus Zone of the Lower Tithonian/"Volgian"–"Portlandian"(see Kutek, 1994b; Kutek, Zeiss, 1974, 1997; *cf.* also Dembowska, 1962, 1973; see also Appendix). The occurrence of ammonites diagnostic of the successive zones of the Lower Tithonian ("Lower to lowermost Middle Volgian") in deposits attaining only about 2.6 m in thickness (1066.0–1063.4 m) indicates a very slow sedimentation rate in a deep-water environment below the fair-weather wave base.

When comparing the deposits of the Pałuki Formation in the Nidzica IG 1 section with those of the Olsztyn IG 1 borehole (Fig. 2) some general comments can be also given. Although these deposits were not fully-cored in Olsztyn IG 1 which precludes some detailed correlations, their general lithological characteristics in both cores is generally similar: the deposits are dominated by shales (especially in their lower and uppermost parts) typical of the Pałuki Formation, but some upper parts being more silty to sandy in character resemble somewhat the Łyna Formation (*cf.* Dembowska, Malinowska, 1977). The thickness of the whole stratigraphical interval corresponding to the formation discussed is, in Olsztyn IG 1, however, about twice that in Nidzica IG 1 (at least 60 m *versus* 38.4 m); the same refers also to the amoeboceras horizon of the Upper Kimmeridgian (at least 38 m *versus* 15 m). The cored interval of the amoeboceras horizon yielded here abundant cardioceratid ammonites partly described by Malinowska (2001), including especially common *Nannocardioceras krausei* (Salfeld) noted throughout the whole interval (from 811–810 m see Malinowska, 2001, pl. 12: 7, 8, and up to 777.7 m where the specimen described to as "*Amoeboceras* sp." by Malinowska, 2001, pl. 8: 7, but belonging to that species, came from). Worth noting is the occurrence of *Hoplocardioceras elegans* (Spath) at the top of the discussed interval at 778 m (described as "*Amoeboceras* (*Amoebites*) *beaugrandi* (Sauvage)" by Malinowska, 2001, pl. 1: 1, which in fact resembles very much the inner whorls of *H. elegans* illustrated *e.g.* by Birkelund, Callomon, 1985, and Wierzbowski, 1989): this indicates that the stratigraphical ranges of that species and of the genus *Nannocardioceras* were similar, and partly overlapped (*cf.* Wierzbowski, Wierzbowski, 2019). At least, it should be noted, that although deposits of the limestone-marly-coquina formation (V) were not recognized in the Olsztyn IG 1 section, they possibly have their counterparts in some parts of the non-cored interval directly below the Pałuki Formation at 830–813 m where the occurrence of carbonate deposits followed by clayey-marly deposits was recognized in the geophysical data (Dembowska, 1977).

The highest Jurassic beds in the Nidzica IG 1 section (1063.4–1046.7 m) consist of marls and limestones attributed to the Kcynia Formation (VII-limestone-evaporatic formation of Dembowska, 1979). Lower and middle beds (1063.4–1049.9 m), 13.5 m in thickness, represent a normal marine environment. The fauna especially at the top of this interval (1053.2–1049.9 m) becomes remarkably prolific, consisting of numerous brachiopods (*Septaliphoria*, "*Terebratula*"), serpulids and bivalves (*Gervillia*, *Perna*, *Ostrea*) (Dembowska, 1962). This is the Brachiopod Bed of Dembowska (1973) correlated originally with the boundary beds between the "Lower" and "Middle Portlandian", and having a regional correlation value, as a unit delimiting the lower part of the Kcynia Formation which originated in fully-marine conditions, as distinct from its upper part which was formed in a restricted marine environment. These deposits in the Nidzica IG 1 borehole did not yield any ammonites, but they can be correlated with similarly developed deposits in Owadów–Brzezinki quarry in the north-western margin of the Holy Cross Mts. which contain ammonites of the uppermost Scythicus Zone to lowermost Virgatus Zone (Matyja, Wierzbowski, 2016): this stratigraphical interval correlates with the boundary beds between the Lower and the Upper Tithonian. The uppermost beds in the Nidzica IG 1 section, 3.2 m in thickness (1049.9–1046.7 m), occurring directly below the erosional boundary with the Lower Cretaceous, are marls to clays and silty marls showing dolomite interbeds. These deposits contain a very poor and monotonous fauna of serpulids and small bivalves.They correspond possibly already to the upper part of the Kcynia Formation, representing a non-fully marine environment.

The corresponding interval in the Olsztyn IG 1 borehole closing the Jurassic succession shows the occurrence of silty marls and limestones, at the top with abundant brachiopods, serpulids and bivalves, correlated with the "Middle and Lower Portlandian", and below the erosional contact with the Lower Cretaceous deposits (Dembowska, Malinowska, 1976; Dembowska, 1977).

NORTHERN PART OF THE PŁOCK TROUGH: ALONG THE MARGINAL ZONE OF THE SHALLOW-WATER CARBONATE PLATFORM

The boreholes located south-westwards from Nidzica IG 1 as considered herein provide a continuous section of the Upper Jurassic – from borehole Działdowo 1, through Działdowo 2 (and neighboring Żuromin 1 and Żuromin 5) to the environs of Lipno (boreholes Lipno 1, Lipno 2 and Lipno 4) – which can be recognized as typical of the northern part of the Płock Trough, and the marginal zone of the carbonate platform. The succession begins with the sponge-limestone formation which attains consequently a marked increase in thickness toward the south-west: from 66.3 m in Nidzica IG 1, 107 m in Żuromin 5, and even 185–210 m in Lipno 2 and 1 (see Dembowska, 1970; Kutek *et al.*, 1973; Fig. 3). Although one of the reasons for the larger thickness of the deposits is an increase in subsidence towards the Middle Polish Trough in the south-west, the sudden growth in thickness of these deposits in the Lipno area needs additional explanation. The biostratigraphical documentation at Lipno is very poor which makes difficult the precise dating of the deposits, nevertheless both the succession of the sponge limestones and their large thickness are very similar to those cropping out in the large quarries at Barcin in the Zalesie Anticline of the Kujawy area, which provides some additional information on their age and development (Matyja, Wierzbowski, 1985; Matyja *et al.*, 1985). The characteristic lithological feature in the cores at Lipno is the common occurrence of marly to silty-marly interbeds in the upper part of the sponge-limestone formation, of 25–30 meters in thickness (Kutek *et al.*, 1973). A very similar succession is observed at Barcin, where the biohermal sponge limestones are replaced laterally and followed towards the top by marly deposits, additionally, ammonites occurring in marly deposits directly above the sponge limestones, are indicative here of the lowermost Kimmeridgian (Bimammatum to Planula zones) (Matyja, Wierzbowski, 1981, 2002; Wierzbowski, 2022). The data strongly suggest that the deposits of the sponge-limestone formation in the boreholes at Lipno, and those cropping out at Barcin are of similar age, and range stratigraphically very close to the Oxfordian/Kimmeridgian boundary. On the other hand, the growth of sponge-microbial buildups at Barcin occurred very promptly, as shown by the occurrence of the ammonites *Microbiplices microbiplex* (Quenstedt) and *Amoeboceras ovale* (Quenstedt) in marly deposits, both indicative of the lower part of the Hypselum Zone of the Upper Oxfordian, at about 35 meters only above the base of the Upper Jurassic, on the flank of the buildups (Matyja *et al.*, 1985). The phenomenon of a sudden growth of buildups was possibly strongly stimulated by movements of the Zechstein salts within the Zalesie structure, and it possibly occurred during the Late Oxfordian as a consequence of the syndepositional tectonic uplift of the salt-anticline: a final consequence of this growth was settlement of the coral bioherms on the top of the sponge-microbial buildups (Matyja, Wierzbowski, 1985). It can be thus safely assumed that the sponge-limestone formation in the Lipno area, similarly to that of the Barcin area, ranged stratigraphically higher than in the Nidzica IG 1 section, replacing laterally at least deposits of the lower part of the coral formation from the latter locality.

The limestone-marly formation (II) represented by micritic limestones with marly intercalations occurs at Lipno

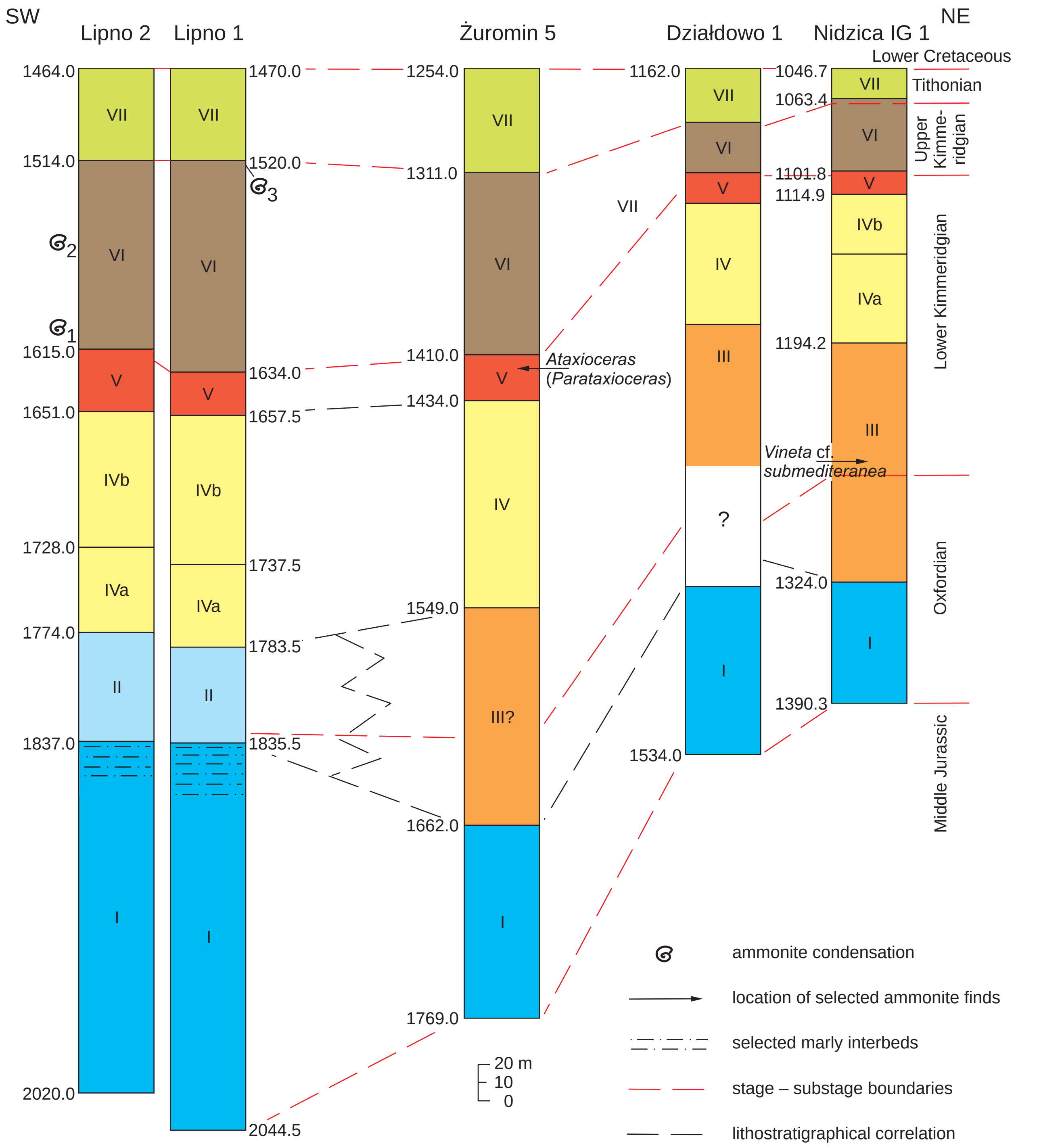


Fig. 3. Lithostratigraphical and chronostratigraphical correlation of the Upper Jurassic deposits in boreholes along the northern margin of the shallow-water carbonate platform (based on Dembowska, 1970, 1973, 1983; Kutek *et al.*, 1973; Niemczycka, 1983; partly modified)

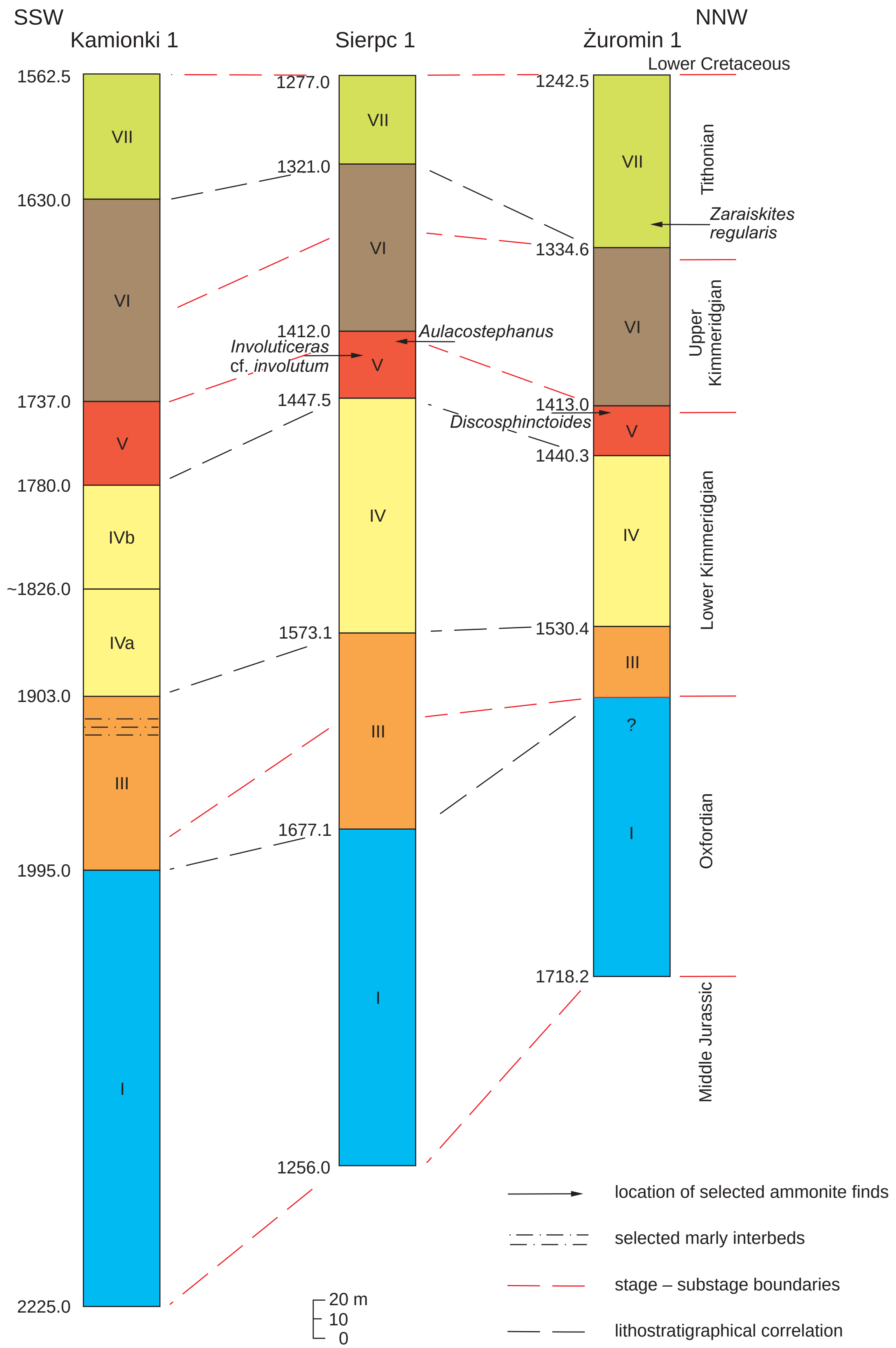
Numerical explanations of the formations (after Dembowska, 1979) are as follows: I – sponge limestone formation (Częstochowa Sponge Limestone Formation); II – limestone-marly formation (Pilica Formation); III – coral formation; IV – oolitic formation (IVa – chalky limestone unit; IVb – oolitic limestone unit, as recognized herein); V – limestone-marly-coquina formation (Nidzica Member as proposed herein); VI – shale-marly-siltstone formation (Pałuki Formation); VII – limestone-evaporatic formation (Kcynia Formation). The most important ammonite occurrences from the Middle Oxfordian to the Kimmeridgian are indicated in the figure. The separately distinguished ammonite condensations within the Upper Kimmeridgian are as follows: (1) *Aulacostephanus* cf. *pseudomutabilis*, *Glochiceras*, *Taramelliceras*, Lipno 2: 1615.0–1610.0 m; (2) *Aulacostephanus jasonoides* and *Sarmatisphinctes subborealis*, Lipno 2: 1556.0–1550.0 m; (3) *Aulacostephanus autissiodorensis*, *A. undorae* and *Sarmatisphinctes subborealis*, Lipno 1: 1524.2–1519.9 m. Location of the section is shown in Figure 1 only, directly above the limestone-sponge formation. These deposits attaining from 52 to 63 m in thickness in boreholes Lipno 1 to Lipno 2 (Fig. 3) were referred in the past to as the “lower member” of the coral-oolitic formation by Kutek *et al.* (1973). It is the equivalent of the “bluish limestones” and lithographic limestones in the Kujawy area (Marek, 1961) showing also large differences in thickness (*c.* 130 m compared with over 200 m), and occurring directly above sponge limestone deposits, and below the oolitic formation (IV). These deposits contain scarce macrofaunal rests, and a very poor assemblage of foraminifers (Bielecka, 1961). They correspond to the Pilica Formation, distinguished originally in the Polish Jura range in central Poland, which includes units of micritic limestones and marls with a poor benthic faunal content. These deposits commonly occur in depressions (basins) between the biohermal complexes of the sponge limestone formation (Częstochowa Sponge Limestone Formation), and contain sometimes redeposited material from the bioherm areas, but also directly rest on bioherms (Matyja, Wierzbowski, 2004). Such a close relation between sponge limestones of the Częstochowa Sponge Limestone Formation and the micritic limestones of the Pilica Formation in the Polish Jura area strongly suggests a similar relation between the discussed deposits at Lipno. This could indicate the presence of the sponge-microbial biohermal complex at Lipno (similarly as in the Barcin area, as discussed above) the development of which was tectonically controlled similarly to those in the Polish Jura (*cf.* also Matyja, Wierzbowski, 2004). Additionally, it is worth noting, that the deposits of the limestone-marly formation (=Pilica Formation) occur in the Płock Trough only in the areas adjoining the Mid-Polish Swell (at its part corresponding to the Kujavian Swell; see Dembowska, 1983) which during the Late Jurassic were located at the boundary of the Middle Polish Trough, being the major tectonically controlled zone corresponding to the edge of the East European Platform (*e.g.*, Dadlez, 1997; Marek, 1997). The deposits of the Pilica Formation as recognized in the Polish Jura and the Holy Cross Mountains have yielded some ammonites indicative of the uppermost Oxfordian (Hypselum Zone), but mostly of the lowermost Kimmeridgian (Bimammatum Zone, and especially the Planula Zone) (see *e.g.*, Matyja, Wierzbowski, 2014; Wierzbowski, 2017, 2020, 2023). Similarly, an earliest Kimmeridgian age can be possibly proposed for the discussed deposits at Lipno.

The lithostratigraphical classification of the directly younger deposits largely follows that of Dembowska (1979) with the oolitic formation (IV) directly overlying either the limestone-marly (II) formation = Pilica Formation, or the coral formation (III). The oolitic formation comprises, however, carbonates that are varied lithologically. It corresponds to two informal units of the coral-oolitic formation as recognized by Kutek *et al.* (1973) at Lipno in the Warsaw Synclinorium: the lower unit dominantly of “chalky” limestones with abundant fauna (IVa), and the upper unit of oolitic and oncolitic limestones (IVb). This subdivision corresponds well to that distinguished in the Holy Cross Mountains, especially in their south-western margin (Wierzbowski, 2020) including: (1) the Bukowa Formation below composed mostly of soft, porous “chalky” limestones often containing oncoids with abundant fossils: hermatypic corals, solenoporoids, bivalves (rudistids and oysters), gastropod nerineids and others, and (2) the Małogoszcz Oolite Formation composed of oolitic (often cross-bedded) and micritic limestones. The recognition of the counterparts of these two formations is not always possible in the studied sections of boreholes in the Płock Trough, but a dominance of oolitic limestones over chalky limestones seems to be observed towards the younger beds of the formation as shown *e.g.*, by Dembowska (1983, fig. 100).

The total thickness of the deposits of the oolitic formation in the northern part of the Płock Trough is generally rather similar (Figs. 3, 4): from 70–80 m in Nidzica IG 1 and Działdowo 1, to about 90–105 m in Żuromin 1 and 5, to about 125 m at Lipno (see Dembowska, 1970; Kutek *et al.*, 1973): it should be remembered that a few meters of the uppermost part of these deposits consisting of siltstones with glauconite, originally attributed to the coral-oolitic formation by Kutek *et al.* (1973), is actually considered as representing a different rock unit (see below). Some differences in the development of the discussed deposits are observed southwards from the area of study, at Sierpc 1 and Kamionki 1 and 2 boreholes (Fig. 4). The coral formation includes here possibly limestones with sponges, corals, bryozoans, brachiopods, bivalves and echinoderms attaining about 90–100 meters in thickness. Some micritic limestones with common marly interbeds occur at the top of this unit, from about 5 to 12 meters in thickness, as seen in Kamionki 1 and 2 boreholes (Dembowska, 1970; Kutek *et al.*, 1973). The oolitic formation (IV) was observed at Sierpc 1 (about

Fig. 4. Lithostratigraphical and chronostratigraphical correlation of the Upper Jurassic deposits across the northern part of the shallow-water carbonate platform (based on Dembowska, 1970, 1973, 1983; Kutek *et al.*, 1973; Niemczycka, 1976a, 1983; partly modified)

Numerical explanations of the formations (after Dembowska, 1979) are as follows: I – sponge limestone formation (Częstochowa Sponge Limestone Formation); III – coral formation; IV – oolitic formation (IVa – chalky limestone unit; IVb – oolitic limestone unit, as recognized herein); V – limestone-marly-coquina formation (Nidzica Member as proposed herein); VI – shale-marly-siltstone formation (Pałuki Formation); VII – limestone-evaporatic formation (Kcynia Formation). The most important ammonite occurrences from the Middle Oxfordian to the Tithonian are indicated in the figure. Location of the section is shown in Figure 1


SSW
NNW
Kamionki 1
Sierpc 1
Żuromin 1
Lower Cretaceous
1562.5
1630.0
1737.0
1780.0
~1826.0
1903.0
1995.0
2225.0
VII
VI
V
IVb
IVa
III
I
1277.0
1321.0
1412.0
1447.5
1573.1
1677.1
1256.0
1242.5
1334.6
1413.0
1440.3
1530.4
1718.2
?
Tithonian
Upper Kimmeridgian
Lower Kimmeridgian
Oxfordian
Middle Jurassic
Zaraiskites regularis
Aulacostephanus
Involuticeras cf. involutum
Discosphinctoides
20 m
10
0
location of selected ammonite finds
selected marly interbeds
stage – substage boundaries
lithostratigraphical correlation

120 m in thickness), and in Kamionki 1 and Kamionki 2 boreholes (123 m, and 118 m, respectively), where it can be subdivided into the lower "chalky" limestone dominated unit (IVa), and the upper unit dominated by oolitic limestones unit (IVb) (Dembowska, 1970; Kutek *et al.*, 1973). The oolitic formation demonstrates considerable thickness increases westwards in the Wojszyce Anticline representing already a transition to the Middle Polish Trough during the Late Jurassic. The formation increases here from about 140 m (Marek, 1961) to even about 210–230 m as recognized in several newly drilled boreholes in that area (Feldman-Olszewska *et al.*, 2012). The marked increase in thickness of the oolitic formation resulted, however, mostly from the development of micritic limestones which may comprise nearly 75% of the whole succession (see detailed description of the Wojszyce IG 1 borehole by Feldman-Olszewska *et al.*, 2012) to the relative limitation of the distribution of oolitic and organogenic limestones.

The generally similar thickness of the oolitic formation retained nearly over the whole area of study points to probable tectonic stability of the basin of deposition. The onset of this type of sedimentation, related to sea-level change, probably mostly climatically controlled, occurred during the Early Kimmeridgian, at the end of the Planula Chron – beginning of the Platynota Chron, as suggested for the northern part of the area of study (see above). Although the areas placed directly to the south did not yield any stratigraphically important fossils, the occurrence here of the specific marly deposits directly below the oolitic formation, as recognized in Kamionki 1 and Kamionki 2, could possibly be considered as an equivalent of the Latosówka Marl Member commonly recognized in central Poland near the boundary of the Planula and Platynota zones (*e.g.*, Wierzbowski, 2023). The suggested interpretation of the argillaceous deposits occurring directly below the lowermost part of the oolitic formation resembles that proposed in the Nidzica IG 1 section as discussed above.

The limestone-marly-coquina formation (V) in the marginal carbonate platform zone from the environs of Nidzica, through Działdowo to Lipno shows some special features of its development. These include the extremely small thickness of the deposits (Figs. 3, 4) when compared with that of the central part of the basin (reaching even 100–200 m in thickness): Nidzica IG 1 (13.1 m), Działdowo 1 (17 m), Działdowo 2 (19.3 m), Żuromin 1 and 5 (24–25 m), Lipno 2 and 4 (about 20 m), and also their special lithological characteristics. The deposits are detrital glauconitic sandy bioclastic limestones and oolitic limestones followed by deposits to large degree siliclastic in composition – from marly siltstones to fine-grained sandstones; clay and shale beds are sometimes developed at the base. They deserve to be distinguished as a new member within the formation which is called herein the Nidzica Member (see Appendix). The deposits of the member are laterally replaced successively towards the south by limestones and marls with intercalations of *Nanogyra* coquinas, subordinately only containing interbeds of siltstones, generally attaining a much larger thicknesses (Sierpc 1 – 35.5 m; Kamionki 1 – 43 m) (Dembowska, 1983; Niemczycka, 1983).

Some ammonites have been recorded in boreholes in the formation: (1) *Ataxioceras* (*Parataxioceras*) sp. (at 1416,5 m in Żuromin 5 borehole) (Pl. 1: 6) which is indicative of the Hypselocyclum Zone; (2) *Involuticeras* sp. (at 1424.6 m in Sierpc 1 borehole) (Pl. 1: 7) originally referred to as "*Ataxioceras* sp." (*e.g.*, Niemczycka, 1983), and *Aulacostephanus* sp. (at 1418.5 m in Sierpc 1 borehole) (Pl. 2: 5) – the former allows correlation with the Hypselocyclum to Divisum zones, the latter possibly with the Mutabilis Zone; (3) *Discosphinctoides* (at 1416.5 m in Żuromin 1 borehole) (Pl. 1: 8) suggesting correlation with some parts of the lower Upper Kimmeridgian. As a whole the discussed ammonite assemblage can be treated as indicative of the upper part of the Lower Kimmeridgian, and some lower parts of the Upper Kimmeridgian (see also Appendix).

Additionally, there may be considered here the stratigraphical position of the ammonite assemblage consisting of *Aulacostephanus* (*A.* cf. *pseudomutabilis* (de Loriol) as interpreted herein), *Glochiceras*, *Taramelliceras*, and a fragmentarily preserved ataxioceratid from Lipno 2 borehole attributed originally to the 1665–1663.5 m interval by Kutek *et al.* (1973, pl. 1: 5). The assemblage was discovered in the core within oolitic-oncolitic limestones referred to an upper part of the oolitic formation (IVb), and as such has been treated by these authors who considered it the earliest ammonite fauna of the Late Kimmeridgian age of that formation. However, this interpretation was questioned by Dembowska (1983) and Niemczycka (1983) who suggested that the discussed fragment of core with ammonites originally came from younger deposits and was erroneously placed within an older part of the succession. This opinion seems to be accepted also because the deposits which yielded the discussed ammonites are marly siltstones with quartz, muscovite and glauconite being closely comparable to those occurring higher in the succession – in the next cored-interval in Lipno 2 borehole at 1615–1610 m. Just this core-interval has been treated as directly overlying the top of the limestone-marly-coquina formation as shown by the geophysical data (Niemczycka, 1983). If there were not any other, *e.g.*, disturbances of tectonic nature in the core, this could indicate that the discussed assemblage of ammonites belonging to the Eudoxus Zone of the Upper Kimmeridgian came directly from above the top of the limestone-marly-coquina formation (V), being comparable to that of the sub-amoeboceras horizon (*cf.* Dembowska, 1965) of the Pałuki Formation.

It additionally supports the older views (*e.g.*, Dembowska, 1962) that the uppermost part of the limestone-marly-coquina formation corresponds already to some lower parts of the Upper Kimmeridgian.

The shale-marly-siltstone (VI) = Pałuki Formation can be easily recognized in the boreholes in the northern part of the Płock Trough. These open-marine deposits rich in ammonites include the Upper Kimmeridgian representing the dominant part of the succession and the Lower Tithonian (see Dembowska, 1965, 1970; Kutek, Zeiss, 1997). A part of the Upper Kimmeridgian corresponds to the very characteristic faunal level rich in small-sized ammonites of the genus *Nannocardioceras*, recognized as the amoeboceras horizon. It is the very characteristic horizon developed at the boundary of the Eudoxus Zone and the Autissiodorensis Zone as the organic-rich shale beds within the Upper Kimmeridgian succession (Wierzbowski, Wierzbowski, 2019).

The lateral thickness variation of the Upper Kimmeridgian deposits of the Pałuki Formation is quite large (Figs. 3, 4). The smallest thicknesses are recorded in the north-eastern corner of the area of study in the boreholes Nidzica IG 1 and Działdowo 1 (35.8 and 25 m, respectively). The thickness increases to the south-west near Żuromin (in boreholes Działdowo 2 – 52 m, and Żuromin 1 and 5 – even up to about 75 m), and Lipno (about 100 m), and similarly towards the south (boreholes Sierpc 1 – 54 m and Kamionki 1 – about 45 m) (Dembowska, 1970, 1983; Kutek *et al.*, 1973; Niemczycka, 1983). The general increase in thickness in the whole area is, however, north-westwards as seen in the northern part of the area of study, and southwestwards in its southern part. This can be interpreted also from the map of Dembowska (1983, fig. 103) although it shows the thickness of a larger stratigraphical interval of the Kimmeridgian corresponding not only to the Pałuki Formation but also to the underlying limestone-marly-coquina formation. Such a general thickness pattern of deposits does not exclude some smaller-scale thickness variations like that in the Żuromin–Płońsk Trough (see *e.g.*, Dembowska, 1983; Niemczycka, 1983; see also Dadlez, Marek, 1969), the stratigraphical interpretation of which is, however, beyond the scope of the present study.

The Lower Tithonian part of the Pałuki Formation is extremely thin in borehole Nidzica IG 1 (only 2.6 m) but it has yielded ammonites representing a wide stratigraphical interval from the Klimovi Zone up to the Scythicus Zone (see above) which indicates stratigraphical condensation (Figs. 2, 3). Unfortunatelly, the precise stratigraphical data on the thickness of coeval deposits in other boreholes in the northern part of the Płock Trough are mostly not known because they were not cored. Some data refer to the Lipno 1 borehole only where Dembowska (1970) suggested a stratigraphical discontinuity at the Kimmeridgian/Tithonian boundary which resulted in a lack of sediments belonging to the Lower Tithonian ("Lower Portlandian" and a part of the "Middle Portlandian", or "Lower Volgian" and a part of the "Middle Volgian" see also Kutek *et al.*, 1973) in the Pałuki Formation. This interpretation was subsequently questioned by Niemczycka (1983) who considered the contact to be tectonic. She suggested moreover that the 42 m thick upper part of the Pałuki Formation in neighboring borehole Lipno 2 (1556–1514 m) is of Early Tithonian age, and that this part of the succession was tectonically eliminated from the adjoining Lipno 1 section, whereas the large thickness of the Kimmeridgian Pałuki Formation in that borehole (about 114 m) resulted from tectonic repetition (see Niemczycka, 1983, figs 2, 5). The deposits corresponding to the alleged Kimmeridgian/Tithonian boundary interval in cored fragment 1556–1550 m in Lipno 2 borehole yielded, however, some ammonites which although originally determined generally as "*Aulacostephanus* sp. " in Kutek *et al.* (1973, pl. 1: 7) and " Virgatosphinctinae (? *Subplanites* sp.)" in Kutek *et al.* (1973, pl. 1: 9) can actually be determined more precisely. The former is *Aulacostephanus jasonoides* (Pavlov), the latter is *Saramatisphinctes subborealis* (Kutek et Zeiss), both indicative of the Autissiodorensis Zone of the Upper Kimmeridgian (*cf.* Kutek, Zeiss, 1997). This indicates thus that the deposits in the Lipno 2 borehole from 1556–1550 m represent still the Upper Kimmeridgian, and not the Lower Tithonian, and that the overlying part of the Pałuki Formation can be also, at least partly, of the Kimmeridgian age. On the other hand, the topmost part of the Pałuki Formation (1524.2–1519.9 m) in Lipno 1 borehole has also yielded some ammonites. These originally were described as: "*Aulacostephanus* cf. *pseudomutabilis* (Loriol)" and "*A.* cf. *eudoxus elegans* Ziegler" (*e.g.*, Niemczycka, 1983), which determinations have suggested the presence of the Eudoxus Zone; actually these ammonites are re-interpreted herein as *Aulacostephanus autissiodorensis* (Cotteau) (Pl. 2: 1) and *A. undorae* (Pavlov) (Pl. 2: 3) which indicates the Autissiodorensis Zone (*e.g.*, Ziegler, 1962). This is generally in full agreement with the occurrence at the same interval in the core of the ammonite originally described as "*Virgataxioceras* cf. *magistri* (Ilovayski et Florenski)" which is *Sarmatisphinctes* closely related to the typical forms of *S. subborealis* (Kutek et Zeiss) (Pl. 2: 4). The data (see also Appendix) strongly suggest that there is a fairly large thickness of the uppermost Kimmeridgian in both boreholes at Lipno, excluding any large tectonic disturbances in the succession. They support also the older opinion of Dembowska (1970) on the strong reduction in thickness of the Lower Tithonian deposits.

The Lower Tithonian deposits of the Pałuki Formation in other areas of the northern part of the Płock Trough are also of small thickness (Figs. 3, 4), *e.g.*, at Żuromin where they attain up to several meters in thickness only: the deposits are arenaceous, especially in their lower parts, and reveal the presence of glauconite (Dembowska, 1973), possibly they could be correlated with the Żnin Member (see also below). More southwards, the Lower Tithonian is, however, markedly thicker. It is *e.g.*, recognized in borehole Sierpc 1: although the lowermost part of the succession corresponding to the "Lower Volgian/Lower Portlandian" is about 2.5 m in thickness (1359.5–1357.0 m) here, being represented by marly siltstones, but a higher part of the succession corresponding to the Scythicus Zone of the "Middle Volgian/ Portlandian" is already 28 m thick, and is represented by marly siltstones showing the common occurrence of silty-marly limestone intercalations upwards (Dembowska, 1973; Niemczycka, 1983). Similarly, a markedly larger thickness of the Lower Tithonian deposits is reported from Kamionki 1 borehole where an ammonite which is comparable with *Ilowaiskya* ex gr. *klimovi* (Ilovaisky) indicative of the lowermost part of the Tithonian ("Portlandian", "Volgian") was found about 60 meters below the top of the Pałuki Formation (Kutek *et al.*, 1973; Niemczycka, 1983).

The characteristic arenaceous-silty-oolitic unit recognized as the Żnin Member occurs in the northern part of the Płock Trough and in the adjoining part of the Mid-Polish Swell (Dembowska, 1970, fig. 101; 1979). It was originally attributed to the uppermost Kimmeridgian (*e.g.*, Dembowska, 1979, tab. I), but as shown at Barcin, the corresponding oolitic deposits are of the earliest Tithonian ("Volgian") age (Kubiatowicz, 1983; Matyja *et al.*, 1985). Such a stratigraphical position of the member was suggested also for other areas of its occurrence (Matyja, Wierzbowski, 1981).

The uppermost part of the Jurassic succession in the northern part of the Płock Trough is developed as limestones and marls, becoming more silty towards the east. They correspond to the lower part of the limestone-evaporitic (VII) formation = Kcyna Formation of Dembowska (1979; see also Figs. 2–4). Their lowermost part is rich in benthic fauna, especially brachiopods and serpulids. Most prominent here is the Brachiopod Bed which attains from about 0.5 m (Lipno 1 borehole) to about 10 m in thickness at Żuromin 1, although it is underlain here by a less fossiliferous limestone interval. The overlying deposits are commonly marly limestones containing locally serpulids and small bivalves ("*Corbula*") (Dembowska, 1973). These are the youngest marine deposits distinguished by Niemczycka (1983) as the the Malice Corbula Limestone Member.They are overlain by marls and clays deposited in a restricted marine environment, followed by salinary deposits (gypsum and anhydrites).

The discussed fully marine deposits of the Kcynia Formation were attributed to the "Middle Portlandian" and/or "Middle Volgian" (Dembowska, 1973; Niemczycka, 1983). They did not yield, however, very numerous ammonites, although some of them are of stratigraphical importance. This is the case of "*Zaraiskites* sp." coming from some lower parts of the Brachiopod Bed in Żuromin 1 borehole at 1323.4 m (Dembowska, 1973, fig. 4; pl. 6: 6), which is *Zaraiskites regularis* Kutek diagnostic for the lower horizon (*regularis* horizon) of the Zarajskensis Subzone of the upper Scythicus Zone (Kutek, 1994b). This indicates that the stratigraphical interval represented by the marine limestones of the lower part of the Kcynia Formation in the northern part of the Płock Trough corresponds to the upper part of the Scythicus Zone, and possibly some lower parts of the directly younger Virgatus Zone. It corresponds thus chronostratigraphically to similarly developed deposits from Owadów–Brzezinki quarry in the north-western margin of the Holy Cross Mountains as described by Matyja and Wierzbowski (2016), corresponding already to the boundary interval between the Lower and the Upper Tithonian.

HISTORY OF SEDIMENTATION

The general facies pattern during the Oxfordian and the earliest Kimmeridgian in areas of the Mazury–Suwałki Elevation and the adjoining part of the Peri-Baltic Syneclise revealed a strong lateral variation well shown by comparison of the sections observed in the Nidzica IG 1 and Olsztyn IG 1 boreholes (Fig. 2). The Nidzica IG 1 borehole in the south shows the development of limestones of the siliceous sponge megafacies (sponge-limestone formation I = Częstochowa Sponge Limestone Formation), ranging stratigraphically from the Lower Oxfordian to the Middle Oxfordian, and possibly up to some lower parts of the Upper Oxfordian, and the overlying limestones of the coralliferous facies with hermatypic corals (coral formation III) of the Upper Oxfordian to the lowermost Kimmeridgian. This is the onset of a typical carbonate platform succession or the platform facies domain – generally indicating the transition from the deep-neritic environment to shallower water conditions. On the other hand, the Olsztyn IG 1 borehole in the north shows the coeval deposits developed in the silt to mud dominated deep-water facies of the Łyna Formation. These deposits in the Olsztyn IG 1 borehole are of markedly smaller thickness, developed as siliciclastic-marly deposits, the only exception being a thin limestone interval possibly of Middle Oxfordian age (?sponge facies), unfortunately not cored in the borehole.

The Nidzica IG 1 and Olszyny IG 1 boreholes located at the northern and north-western slopes of the Mazury–Suwałki Elevation, as well as numerous boreholes in the Peri-Baltic Syneclise in the north, are the key-sites in palaeogeographical reconstruction and facies analysis of the first shallower-water deposits represented by coralliferous deposits and the coeval siliciclastic deposits of their foreland. The base of the coralliferous limestones in the Nidzica IG 1 and Olszyny boreholes is located at 74 m and about 90 m, respectively, above the base of the Upper Jurassic. The thickness of the siliciclastic deposits of the Lower to Upper Oxfordian is markedly smaller in the Olsztyn IG 1 borehole (about 12 m only) but it gradually increases from about 40 m in the Gołdap IG 1 borehole, through about 50 m in the Bartoszyce IG 1 borehole, to about 80 m in the Pasłęk IG 1 borehole (*cf*. Wierzbowski *et al*., 2015). This demonstrates clearly that the siliciclastic material for the Łyna Formation derived from the north-west, and, on the other hand, reveals the contrast in thickness of the siliciclastic deposits when compared with the coeval sponge carbonate deposits in the south (excluding additionally an uppermost part of the siliciclastic deposits, from a few meters in the Olsztyn IG 1 core to 10–20 meters in thickness in other boreholes being the lateral equivalent of a lower part of the coralliferous deposits, see also below). The difference resulted possibly from the existing palaeorelief of the sea-bottom directly preceding the appearance of the coralliferous facies – between the gentle slope of the silty to clayey deposits in the north-west, to the prominent edge of the carbonate ramp in the south. It should be remembered that the existing differences in thickness of these and younger Upper Jurassic deposits cannot be interpreted as the consequence of tectonically controlled subsidence only. In such an interpretation the term Suwałki Embayment applied for the frontal part of the carbonate deposits of larger thickness in north-western Poland is unfortunate because it suggests the presence here of a depressed area during their sedimentation (*cf*. Niemczycka, Brochwicz-Lewiński, 1988).

The most eminent biostratigraphical unit of the Łyna Formation is the radiolarian horizon comprising mostly clays, marls and marly siltstones showing the mass occurrence of radiolarians, planktic foraminifers, and calcareous nannofossils (Smoleń *et al.*, 2014; Wierzbowski *et al.*, 2015), very widely recognized in boreholes in the Peri-Baltic Syneclise. It represents the lowest part of the Kimmeridgian – the Bauhini Zone. The thickness variation of the horizon is recognized as ranging in central parts of the basin from about 20–25 m (Gołdap IG 1, Bartoszyce IG 1 boreholes) to at least about 30 m in the Olsztyn IG 1 borehole, but the horizon itself attains about 1 m only on the elevated block in northern part of the basin (Pasłęk IG 1 borehole). The composition of the microfaunal assemblage of the radiolarian horizon strongly suggests the presence of nutrient-rich waters, whose occurrence resulted from a sudden change in water circulation. Additionally, because of strong contrasts in thickness of the radiolarian horizon, a diversified relief of the sea-bottom can be presumed. This can explain the very poor assemblage of benthic foraminifers possibly resulting from partly anoxic bottom waters. It is in general accordance with the common development of small-sized ammonites, both cardioceratids (*Plasmatites*) and oppeliids (*Metahaploceras*, *Glochiceras*), adapted to a nectopelagic environment. The deposits occurring directly beneath the horizon show commonly the features of a small sedimentation rate or even local erosion at the top due to current activity, including the occurrence of phosphorites (Wierzbowski *et al.*, 2015). All these observations suggest the tectonic control of sedimentation in the Peri-Baltic Syneclise during the latest Oxfordian – earliest Kimmeridgian: with its central part strongly subsiding, but some other parts becoming elevated as well (Wierzbowski *et al.*, 2015).

The coeval coralliferous limestones are developed in the elevated areas located southwards of the Peri-Baltic Syneclise during the latest Oxfordian – earliest Kimmeridgian, being only locally affected by sedimentation of deeper-water radiolarian clays and marly siltstones. Such a case is represented by a thin interbed of micritic limestones containing possibly radiolarians, as seen in the Nidzica IG 1 core at 1260.5–1257.7 m, near the place of discovery of the aulacostephanid (*Vineta*) ammonite, and near the Oxfordian/Kimmeridgian boundary. This strongly suggests that only the upper part of the coralliferous deposits (coral formation) corresponds to the radiolarian horizon, whereas their lower part is possibly equivalent to a much thinner, poorly recognized stratigraphical interval of the Łyna Formation, locally rich in phosphorites, and possibly of markedly reduced sedimentary thickness: the topmost part of this interval was recognized *e.g*., in the Bartoszyce IG 1 and Gołdap IG 1 boreholes (see Wierzbowski *et al.*, 2015, figs. 3, 4), but unfortunately was not cored in the Olsztyn IG 1 borehole (Fig. 2).

The stratigraphical interval of the radiolarian horizon corresponding mostly to the Bauhini Zone of the lowermost Kimmeridgian marks thus a new phase in the development of sedimentation at the outer part of the emerging shallow-water carbonate platform and its siliciclastic foreland. The axial part of the Peri-Baltic Syneclise became the place of rather rapid accumulation of organic-origin rich muds and silts, being preceded by a significant and wide-spread regional non-sequence formed at the end of the Oxfordian, marked by very fragmentary sedimentation, erosion and reworking (Wierzbowski *et al.*, 2015). The earliest Kimmeridgian, corresponding to the Bauhini Chron (and coeval Bimammatum and Planula chrons) appears to be a time of a special interaction between the tectonic and climatic factors which resulted in high productivity of the planktic communities. This seems to indicate an episode corresponding to the shelf dysoxic-anoxic event system (SDAE, after Rogov *et al.*, 2020) which ranged from high-latitudes towards the south including partly areas of Central Europe, and the occurrence of a very high sea-level (*cf.* Wierzbowski *et al.*, 2016). These observations are in accordance with a wide development of coralliferous facies at the elevated parts of the basin.

The coralliferous facies which follows the sponge megafacies has been especially well recognized in the elevated parts of the north-eastern margin of the Holy Cross Mountains: the occurrence of massive coral limestones forming flat buildups, containing numerous foliaceous and submassive coral assemblages, has been treated there as indicative of a deeper-water environment devoid of stronger-water activity (Roniewicz, Roniewicz, 1971). The foundation of the coral buildups took place during the latest Middle Oxfordian, and their progradation continued during the beginning of the Late Oxfordian, in the Bifurcatus Chron as evidenced by ammonites (Gutowski, 1992, 1998; Brochwicz-Lewiński, Liszkowski, 1976). The development of the coral buildups in the north-eastern margin of the Holy Cross Mts. was controlled by synsedimentary tectonic uplift along the fault zone (Wierzbowski, 2023). The final stage of development of the coralliferous facies diachronously placed towards the west is observed in the late Planula Chron of the Early Kimmeridgian, both in the south-western-margin of the Holy Cross Mountains and in the Częstochowa Upland (Matyja, 1977; Matyja, Wierzbowski, 1996; Wierzbowski, 2023). It is worth noting that a similar development of coral deposits was proposed also for the Jura Mountains in northern Switzerland: the formation of the coral patch reefs of the Gùnsberg Member/Formation at the margin of the platform ("Celtic" facies domain) and their following progradation onto the basinal ("Argovian") facies took place just during the early Late Oxfordian – the Bifurcatus Chron, with its onset already at the boundary between the Middle and Late Oxfordian, at the transition from the Transversarium to Bifurcatus chrons (*e.g.*, Gygi, 1995, 2000). The final stage in progradation of the coralliferous facies was observed during the Early Kimmeridgian when the Verena Member and the Olten Member began to develop coral bioherms (Gygi *et al.*, 1998, fig. 3; Gygi, 2000). The phenomenon was possibly controlled by synsedimentary tectonic activity due to the reactivation of the older Paleozoic basement structures which resulted in a sudden change of subsidence rate between the "Celtic" and the "Argovian" facies areas during the early Bifurcatus Chron (Allenbach, 2001). The development of the coralliferous facies in north-eastern Poland (as seen in Nidzica IG 1 and Olszyny boreholes) bounding along the NE–SW directed zone to the siliciclastic facies of the Łyna Formation from the north (boreholes Gołdap IG 1, Bartoszyce IG 1, Olsztyn IG 1, Pasłęk IG 1) (see Niemczycka, 1976a, fig. 63; see also Wierzbowski *et al.*, 2015) seems to be also tectonically constrained.

Another problem in correlation appears when one considers the relation between the sponge-limestone formation (I = Częstochowa Sponge Limestone Formation) and the marly-limestone formation (II = Pilica Formation) as seen along the marginal zone of the shallow-water carbonate platform in the northern part of the Płock (Warsaw) Trough. Strong development of the marly-limestone formation ("bluish limestones" and lithographic limestones of Marek, 1961) and sponge limestones occurred in the westernmost part of the Płock Trough at the contact with the Mid-Polish Swell (Kujavian Swell): this corresponded originally to the tectonically-controlled border zone of the Middle Polish Trough during the Late Jurassic. Displacement of the basement blocks and successive activation of the Zechstein salts resulted in strong synsedimentary tectonic deformations as shown both in the facies development and thickness differences of the Oxfordian to lowermost Kimmeridgian deposits. The time and spatial relations between the sponge and cyanobacteria/microbial-sponge limestones forming the biohermal complexes and micritic limestones and marls of the Pilica Formation, possibly resembled here those known from the Polish Jura and the Holy Cross Mountains – where the original sea-bottom relief between the top of the bioherms and the bottom of the adjoining basins attained at least about 160–200 m during the latest Oxfordian and the earliest Kimmeridgian (Matyja, Wierzbowski, 1996, 2004). The phenomenon undoubtedly resulted from a sudden growth of the sponge-microbial bioherms, and was tectonically-controlled (*e.g.*, Wierzbowski, 2023). This to a large degree explains the appearance of thick micritic-marly deposits in deep basins between the bioherms. The very poor benthic faunal assemblage of these deposits resulted possibly from abundant organic matter in stagnant bottom waters in basins. It should be remembered, that the deposits of the basins show the common occurrence of radiolarian faunas both of Tethyan and Boreal affinity (Smoleń, 2016), as well as several geochemical indices proving a high level of nutrients and increased productivity of sea-water during the latest Oxfordian and the earliest Kimmeridgian, as recognized *e.g.*, in the Wieluń Upland, central Poland (Wierzbowski *et al.*, 2016). All these features indicate marked climatic and environmental fluctuations, and seem to correspond well to the occurrence of the radiolarian horizon in the Peri-Baltic Syneclise of similar age, as discussed above. It is possible that the change of the environment towards a higher productivity of sea-water successively eliminated the development of the siliceous sponge assemblages flourishing rather in the low to moderate nutrient conditions (*e.g.*, Olivier *et al.*, 2004). The phenomenon of rapid growth of sponge-microbial bioherms during the Late Oxfordian (especially during the Bifurcatus Chron) resulted in the formation of very large biohermal complexes well seen in the recent landscape of the Polish Jura range of central Poland, and called by the late XIX – early XX century Polish geologists the "Upper

Massive Limestones" (Polish: "górny wapień skalisty"). The strong development of the sponge-microbial bioherms, as well as micritic limestones and marls which completely infilled the basins (and the deposition of which possibly continued mostly after the rapid bioherm growth) formed the foundation for the forthcoming shallow-water carbonate platform.

The shallow-water carbonate platform deposits begin abruptly with the oolitic formation (IV) of Dembowska (1979) represented by various shallow-water carbonates. Sedimentation as recognized in detail *e.g.*, in the Wieluń Upland took place after a break and uplift. This resulted from climatically-controlled changes related to eccentricity cycles and superimposed tectonic uplift and erosion (Wierzbowski, 2017, 2023). The Latosówka Marl Member of the uppermost Pilica Formation represents the regressive unit with marly deposits. These deposits from 0 to more than 100 m in thickness, occur at the base of the shallow-water carbonate platform and coeval carbonate deposits and smoothed to large degree an older strongly contrasted relief of the sea-bottom, as seen in the Wieluń Upland (Wierzbowski, 2017). The marly intercalations corresponding possibly to the Latosówka Marl Member are commonly recognized in other areas, including the area of study, such as in the Nidzica IG 1 borehole section (see above), and possibly the Kamionki 1 and 2 boreholes (Figs. 2–4), at the top of the coral formation, and near the base of the oolitic formation of Dembowska (1979). During the following growth of sea-level, the chalky limestones with abundant shallow-water fauna commonly appeared. Their occurrence marked the maximum extent of shallow-marine carbonate production, and represented a moderately shallow-marine, fairly uniform environment of a wide carbonate bank.

The onset of deposition of the shallow-water oolitic formation occurred at the end of the Planula Chron – beginning of the Platynota Chron, and formation of these deposits continued nearly to the end of the Hypselocyclum Chron of the Early Kimmeridgian, as shown in the Holy Cross Mountains and adjoining parts of the Wieluń Upland and Częstochowa Upland. The only formal lithostratigraphical units covering the whole stratigraphical interval are: the Bukowa Formation (1), the Małogoszcz Ooolite Formation (2), and the Grabki Formation (3), as distinguished in the south-western margin of the Holy Cross Mountains (Wierzbowski, 2020). Their succession represented changing environmental conditions as follows: from a slight deepening which resulted in the appearance of fairly uniform facies of "chalky" limestones deposited in a relatively quite water-zone (unit 1; see Roniewicz, Roniewicz, 1971), through a localized uplift which induced sedimentation of oolitic limestones and micritic limestones in large shoals, controlled by climatic factors and the related changes of sea-level (unit 2), to uniform sedimentation of micritic limestones and marls in a restricted environment behind the uplifted marginal areas (unit 3; see Wierzbowski, 2020, 2023). Generally, the whole stratigraphical succession comprises deposits from a markedly quiet and uniform environment below, to those formed due to somewhat diversified tectonically-controlled subsidence, above. Such an interpretation can also be proposed for the studied succession of the marginal zone of the carbonate platform in northern Poland, from the "chalky" limestones dominated interval below to the oolitic limestones dominated interval above, respectively.

The discussed succession corresponds well also to the development of sedimentation in the lower part of the Reuchenette Formation (Vabenau Member) in the Jura Mountains in northern Switzerland. These shallow-water deposits show a rather flat morphology of the carbonate platform. They are generally poor in ammonites, although the few described range from the Planula/Platynota boundary zones interval to the Hypselocyclum/Divisum zones boundary interval of the Lower Kimmeridgian (Gygi, 1995; Jank *et al.*, 2006a, b; Comment *et al.*, 2015). It shows that this unit correlates with the oolitic formation and its equivalents in central and northern Poland.

Biodetrital and oolitic limestones followed by silty to sandy beds with glauconite, and shales, generally of small thickness up to about 20–25 meters, particularly well-developed along the northern margin of the carbonate platform in northern Poland, represent a special development of the limestone-marly-coquina formation (V) of Dembowska (1979), called herein the Nidzica Member (Figs. 2–4; see also Appendix). It indicates the availability of coarser material when compared with typical deposits of the formation: marls and marly limestones with interbeds of *Nanogyra* coquina showing a marked increase in thickness towards the south and south-west – from some tens of meters to more than 100 m in thickness in the Kujawy area (*e.g.*, Dembowska, 1965), and 100 m to over 200 m in thickness in the Holy Cross Mountains (Kutek, 1968). These latter deposits comprised the Coquina Formation, which corresponded to the transgressive-regressive sequence LUK (Lower-Upper Kimmeridgian) of Kutek (1994a). They include also several smaller informal lithostratigraphical units from the Holy Cross Mountains, such as Skorków, Brzegi, Staniewice and Top Coquinas, as well as some intervening parts of the succession where the oyster (mostly *Nanogyra*) coquinas occur less commonly, *e.g.*, Top Clays (see Kutek, 1968). On the other hand, the informal unit "Stobnica Beds" distinguished there by Kutek (1961, 1962), the lithologies of which comprise clays, marls and marly limestones with intercalations of *Nanogyra* coquinas, would corresponded precisely to the Coquina Formation. The Stobnica Coquina Formation as proposed by Matyja and Wierzbowski (2014) is just the equivalent of the limestone-marly-coquina formation of Dembowska (1979).

The stratigraphical range of the formation, especially well biostratigraphically recognized in the Holy Cross Mountains, is from the upper Lower Kimmeridgian (upper Hypselocyclum Zone, and Divisum Zone) to the lower Upper Kimmeridgian (Mutabilis/Acanthicum Zone to lower/middle Eudoxus Zone) (see Kutek, 1961, 1968, 1994a; Wierzbowski, 2023, 2024). The few ammonites found in the Nidzica Member suggest a similar stratigraphical interval from the upper Lower Kimmeridgian to some lower parts of the Upper Kimmeridgian with possibly a substantial erosional hiatus at the top (see above, see also Figs. 2–4).

The development of the limestone-marly-coquina/Coquina = Stobnica Coquina Formation marked generally the decline of the shallow-water platform environment. Sedimentation of the Nidzica Member occurred along the former northern margin of the shallow-water carbonate platform in possibly a tectonically-controlled zone due to renewed uplift at the end of the Early Kimmeridgian. The deposits of the member were allegedly formed along the submarine escarpment in an unstable tectonic environment with the activity of strong currents. The Nidzica Member is rather thinly developed and shows strongly contrasted lithologies with marked lateral changes over relatively short distances corresponding to the especially highly dynamic depositional environment, showing possibly an incomplete succession, intensively winnowed and containing some minor erosional gaps. The topmost part of the member is laterally replaced towards the west and north by the more completely developed siliciclastic succession of the Łyna Formation (Dembowska, 1979).

Although the development of the whole limestone-marly-coquina formation has been correlated with a single tectonic-stratigraphic transgressive-regressive sequence (Kutek, 1994a), the formation is however, not so uniform when considered in detail in its sedimentological character. The occurrence of smaller scale transgressive-regressive cycles delimited by a concentration of ammonite shells at some levels is known in the Holy Cross Mountains, and some adjoining areas: (1) in the Uhlandi Subzone of the Divisum Zone of the uppermost Lower Kimmeridgian; (2) in the upper part of the Mutabilis/Acanthicum Zone of the lowermost Upper Kimmeridgian – especially at the *schilleri* horizon, and (3) at some lower/middle parts of the Eudoxus Zone of the Upper Kimmeridgian. All these high-sea levels can be treated as climatically-controlled, possibly related to long eccentricity cycles, but the upper one seems to be additionally tectonically-controlled (Wierzbowski, 2023, 2024). The Nidzica Member – a highly incomplete equivalent of the limestone-marly-coquina formation = Coquina Formation = Stobnica Coquina Formation – thus owes its origin possibly to several changes of sea-level due to climatic cycles and/or tectonic subsidence, and corresponding periods of sedimentation and erosion, especially strongly accentuated because of special situation where the unit was developed.

Sedimentation of the limestone-marly-coquina formation in central and northern Poland resulted from regional subsidence/sea level rise which led to marly facies being deposited over wide areas. In inner (and more elevated) parts of the older carbonate platform, in the Lublin region of south-eastern Poland, the dominant deposits are also marls and various limestones of the Głowaczów Formation. They are known only from boreholes and did not yield any ammonites. The deposits contain an abundant shallow-water benthic fauna – mostly bivalves, especially mytiloids, myids and oysters, and commonly show erosion surfaces and associated limestone pebbles. The deposits are replaced, however, by the dolomites and anhydrites of the Ruda Lubycka Formation towards the south-east (Niemczycka 1976a, b: Gutowski *et al.*, 2005). On the other hand, the shallow-water limestones with abundant benthic fauna of the northern Jura Mountains of the upper part of the Reuchenette Formation, known from numerous outcrops, have yielded ammonite faunas which occur only in some intervening marly intervals corresponding to high sea-levels. The lowest of them is the Banné Marl Member (Marnes du Banné) strictly corresponding to that of the uppermost Lower Kimmeridgian (mostly Divisum Zone). A younger marly interval with ammonites of the Virgula marls (Marnes à virgula inférieur) showed the presence of a few ammonite horizons located from the boundary between the Mutabilis Zone and the Eudoxus Zone, including the *schilleri* horizon (horizon M3), and the younger horizons, including that defined by the co-occurrence of *Aspidoceras caletanum* (Oppel) and *Aulacostephanus eudoxus* (d'Orbigny) (horizon E3) (Comment *et al.*, 2015; see also Jank *et al.*, 2006a, b). It should be remembered that some of these ammonite horizons, representing the transgressive episodes, are well recognized in a lower part and in an upper part of the limestone-marly-coquina = Coquina = Stobnica Coquina Formation in central Poland (see above; see also Wierzbowski, 2023), which strongly accentuates the wide palaeogeographical similarities in the development of these deposits in epicratonic areas of central Europe.

The Pałuki Formation represents the continuation of the argillaceous sedimentation of the underlying limestone-marly-coquina/Stobnica Coquina Formation. The boundary between these formations is well recognized especially when marly limestones with *Nanogyra* are overlain by monotonous claystone-mudstone-marly deposits which occur in the central parts of the Polish Late Jurassic basin (Dembowska, 1979). When the transition between the formations is developed in siltstone to marly facies – which is known commonly in the marginal parts of the basin – the precise location of the boundary is, however, sometimes difficult. Such a situation occurs *e.g.*, in the Nidzica IG 1 section where the uppermost part of the Nidzica Member, represented by silty marls, can be an age counterpart of the lowest part of the Pałuki Formation (possibly of the sub-amoeboceras level) from the Kujawy area – representing the more central part of the basin. Such a diachronous range of the boundary between the two formations could result from the earlier or later disappearance of the oyster *Nanogyra* assemblage which was related to the occurrence of oxygen-restricted bottom waters (Dembowska, 1965). The Pałuki Formation overlies also the siltstone-dominated Łyna Formation in the marginal parts of the Peri-Baltic Syneclise but the precise location of the boundary is also difficult here.

In spite of all these problems, the development of the clays and shales of the Pałuki Formation indicates that partly dysoxic-anoxic bottom waters prevailed during the Late Kimmeridgian, and that the sediments had accumulated in a fairly deep environment. This was especially well recognized during sedimentation of the organic-rich shales of the amoeboceras horizon with common small-sized *Nannocardioceras* ammonites at the boundary between the Eudoxus to Autissiodorensis chrons. The development of small-sized *Nannocardioceras* took place possibly during a maximum of transgression in the surface waters as nectopelagic forms which flourished when partly anoxic conditions at the bottom prevailed (Wierzbowski, Wierzbowski, 2019). This interval represents thus the subsequent shelf dysoxic-anoxic event system (SDAE, after Rogov *et al.*, 2020). The wide geographical range of these deposits in the Upper Kimmeridgian in the cores studied indicates a marked unification of the facies in the whole area of north-eastern Poland: although the occurrence of silty intercalations within a clayey-marly succession has been generally observed towards the margin of the basin (see Dembowska, 1979). The marked differences in thickness of theses deposits, as *e.g.*, that observed between Nidzica IG 1 and Olsztyn IG 1 boreholes (see Figs. 2–4) could have resulted either from the inherited older topography of the sea-floor or synsedimentary tectonic activity along the former marginal zone of the carbonate platform.

The discussed shales with *Nannocardioceras* from the central parts of the basin corresponding to a high sea level near the Eudoxus/Autissiodorenis zones boundary of the Upper Kimmeridgian have possibly their counterparts in more inner areas of the carbonate platforms in central Europe. The same level corresponds also to the prominent marly interval “Marnes à virgula supérieur” in the Jura Mountains of northern Switzerland which yielded in its lower part ammonites indicative of the topmost part of the Eudoxus Zone (see Jank *et al.*, 2006a, b; Comment *et al.*, 2015). In the inner carbonate platform of southeastern Poland and Western Ukraine this interval can be possibly correlated with the basal part of the Babczyn Formation and the corresponding part of the Niżniów Formation which have a transgressive character and can be interpreted as corresponding to the base of the transgressive-regressive Megasequence III as interpreted by Gutowski *et al.* (2005; see also Niemczycka, 1976a, b), but it is not excluded that these deposits can be younger.

Whereas the lower to middle parts of the Upper Kimmeridgian Pałuki Formation have shown rather poor assemblage of benthic fauna, the uppermost part corresponding to the Autissiodorensis Zone, and representing the sarmatisphinctes (“virgataxioceras”) faunal horizon has revealed already numerous oysters (mostly *Nanogyra*) as well as other bivalves (Dembowska, 1965). It presents the normal deep-water, marine environment. The relevant data from the north-western margin of the Holy Cross Mountains has revealed that the deposits of the uppermost part of the Pałuki Formation, beginning from the Kimmeridgian/Tithonian boundary, are fairly rich here in fine siliciclastic detrital material possibly transported from southern directions (Matyja, Wierzbowski, 2014; see also Wierzbowski, 2023). In the area of study including the northern part of the Płock Trough marked changes in thickness of the Lower Tithonian deposits are also observed (Figs. 3, 4): the deposits are generally of smaller thickness when compared with areas placed westwards and southwards, and they show signs of stratigraphical condensation (although in deep-water facies), and possibly also stratigraphical gaps. Moreover, in the directly adjoining areas to the north, the occurrence of special deposits with oolites, siltstones and glauconite, corresponding to the Żnin Member of the Pałuki Formation of earliest Tithonian age, is recorded. Features such as these suggest the presence of a fault system that was active during the earliest Tithonian. It stretched along an ENE–WSW direction and corresponded possibly to that of the northern margin of the former shallow-water carbonate platform. The end of the Kimmeridgian – beginning of Tithonian displayed thus the time of an unstable tectonic environment in large areas of southern and northern epicratonic Poland, as witnessed by localized periods of uplift and subsidence.

The succeding tectonic activity and the climatic constraints resulted at least during the Late Tithonian in the total isolation of central and northern areas of Poland from the open-sea environment which resulted in the foundation of the next huge shallow-water carbonate platform, the development of which ranged stratigraphically through the earliest Cretaceous.

GENERAL COMMENTS AND CONCLUSIONS

The deposition of the shallow water carbonate deposits constituting the carbonate platform was controlled by the climatic conditions: on a long term-scale influenced by climatic cyclicity, as well as by the tectonic development of the area. Study of the Upper Jurassic deposits seen in deep boreholes in north-eastern Poland has resulted in the recognition of general stages of their sedimentary development, mostly in relation to the appearance or disappearance of the shallow-water carbonate platform environments.The deposits are compared with those situated more towards the south in central Poland, in the elevated areas of the so-called Meta-Carpathian Arch (*cf.* Kutek, 1994a), and actually exposed on the surface. The stratigraphical position and the sedimentary development of these deposits, mostly from the Holy Cross Mountains, have been presented as the result of numerous studies in the past, *e.g.*, by Kutek (1968, 1969), Liszkowski (1976), Matyja (1977, 2011), Matyja *et al.* (1989), Gutowski (1992, 1998), Matyja, Wierzbowski (2014), and Wierzbowski (2020, 2023, 2024). Additionally, there have been considered here the coeval shallow-water (but also intervening deposits of deeper-water origin) of other European areas – especially of the Upper Jurassic of the Jura Mountains in northern Switzerland, *e.g.*, Gygi (1995, 2000), Allenbach (2001), Jank *et al.* (2006a, b) and Comment *et al.* (2015). The development of the whole Upper Jurassic succession can be summarized in nine points as given below.

1. The phenomena heralding the appearance of the shallow-water carbonate platform already took place during the Late Oxfordian, and continued during the earliest Kimmeridgian. They resulted from tectonic uplifts and regional subsidence not only in the area of Poland, but also in other central European areas marking a period of tectonic instability. The large tectonic zones in Poland, becoming active from the boundary between the Middle and Late Oxfordian, and especially during the Bifurcatus Chron, were localized in the south of the Holy Cross Mountains including the Zawiercie–Busko Fault Zone (Matyja, 2009), and in the north of the area of study in NE Poland, at the contact with the Peri-Baltic Syneclise (Wierzbowski *et al.*, 2015; see also above, herein). Both these tectonic zones delimited the boundaries of the future Early Kimmeridgian huge carbonate platform of eastern Poland. The areas north and south of these tectonic zones became the places of deposition of marly to silty deposits: the Łyna Formation in the north (see above), and the lowermost part of the Niwki Formation, occurring directly above the sponge limestone deposits, in the south (Matyja, Barski, 2007; Matyja, 2009). Tectonic activity during the Late Oxfordian was observed also within the area of the future carbonate platform, in the Holy Cross Mts., along the reactivated older faults such as the Grójec Fault Zone and the Nowe Miasto–Iłża–Bałtów Fault Zone (*e.g.*, Wierzbowski, 2023). Everywhere there the tectonic uplift resulted in the sudden growth of sponge-microbial bioherm complexes, and the occasionally there followed the formation of the deeper-water coral buildups which settled the tops of older bioherms. Tectonic activity was inferred also in other European areas: *e.g.*, deposition of the siliciclastic Effingen Member in northern Switzerland occurred simultaneously with the formation of coral bioherms and associated various grained limestones of the Gùnsberg Member/Formation, and took place during the Late Oxfordian (Gygi, 2000), whereas the corresponding facies boundaries were here also related to older faults in the basement reactivated at that time (Allenbach, 2001).
2. The increased subsidence in some areas as the consequence of the large-scale tectonic activity during the Late Oxfordian-earliest Kimmeridgian, resulted possibly in the marked inflow of sea currents bringing the nutrient rich-waters from the north into the set of reactivated or newly originated basins and troughs. Such was possibly the principal reason for the deposition of the above discussed radiolarian horizon in the Peri-Baltic Syneclise during the earliest Kimmeridgian, the origin of which was preceded by strong erosion and/or non-deposition (see also Wierzbowski *et al.*, 2015). The marked changes in ammonite faunas during the Late Oxfordian-earliest Kimmeridgian, shown by the occurrence of the Subboreal to Boreal assemblages as recognized *e.g.*, in the Wieluń Upland, central Poland, correlate also with geochemical data suggesting an increase of biogenic elements and with increase of planktic microfossils – mostly radiolarians (Wierzbowski *et al.*, 2016; Smoleń, 2016). All these phenomena suggest a sudden change in sea-water conditions, and seem to correspond well to the SDAE system (including a set of shelf dysoxic-anoxic events, see Rogov *et al.*, 2020) which possibly occurred that time having a large geographical extent in the central part of Europe.
3. The syndepositional faulting and growth of microbial-sponge and coral buildups resulted in the appearance of a strongly diversified topography of the sea floor in the area of the future carbonate platform (*e.g.*, Matyja, Wierzbowski, 1996). It is documented by the development of submarine fans of various grainstones, and even of gravity flow deposits in the basinal micritic limestones deposited between the bioherms – from the Late Oxfordian to the earliest Kimmeridgian, as seen *e.g.*, in the Holy Cross Mountains and adjoining parts of the Wieluń Upland (*e.g.*, Matyja *et al.*, 1989; Wierzbowski, 2017). The fairly rapid development of the well-bedded

micritic limestones and marls of the basinal Pilica Formation (including the Latosówka Marl Member) was correlated with the general decline of bioherms, and resulted in the gradual smoothing of the original sea-floor. The occurrence of the prominent discontinuity surface above, showing wide distribution and cutting across the diversified facies pattern of micritic limestones to marly deposits and biohermal limestones, strongly suggests the sudden tectonic uplift at the end of the Planula Chron in the south-western margin of the Holy Cross Mts. and in the Wieluń Upland. It marked just here the transition from a diversified sea-bottom relief to fairly uniform carbonate platform conditions (*e.g.*, Wierzbowski, 2017, 2020, 2023). The corresponding transition from the coral formation and its lateral equivalent-the limestone-marly formation (= Pilica Formation) to the overlying oolitic formation in the studied boreholes in north-eastern Poland is not known in detail which precludes the recognition of the possible effect on sedimentation of fault-movements. It is worth noting, however, the occurrence of the prominent marly-silty interbeds at the discussed boundary in some boreholes (Figs. 2–4) which have been compared to the Latosówka Marl Member, suggesting some inflow of siliciclastic sediment, and possibly enabling the correlation with the sections in the Holy Cross Mts. – the Wieluń Upland.

4. The typical deposits of the shallow-water carbonate platform were “chalky” limestones composed of various carbonate grains with abundant and diversified benthic fossils (hermatypic branching and massive corals, solenoporoids, various bivalves, including oysters and diceratids, nerineid gastropods, and others). These were commonly followed by large oolitic limestone units often cross-bedded and laterally replaced by micritic limestones showing locally bands of fine-grained organodetrital-oolitic limestones. The deposits showed their maximal development in a wide area from the Holy Cross Mountains in the south to the studied area of north-eastern Poland during the Platynota Chron and a bulk of the Hypselocyclum Chron of the Early Kimmeridgian (*e.g.*, Wierzbowski, 2020, 2023). Similar deposits were deposited during the same time in other European areas like *e.g.*, the lower part of the Reuchenette Formation in northern Switzerland (see also above). It may be suggested that the discussed shallow-water carbonate succession of the Early Kimmeridgian, having a strongly regressive character, can be interpreted in terms of long time-climatic changes as corresponding to the 1.2 myr arid interval of the about 2.4 myr duration long-term climatic cycle (*cf.* Grabowski *et al.*, 2021).

5. The development of the discussed shallow-water carbonate deposits was suddenly stopped by tectonic activity, and possibly by the occurrence of more humid climatic conditions during the late Hypselocyclum Chron. These phenomena were responsible for the development of the new transgressive-regressive tectono-stratigraphic LUK sequence of Kutek (1994a). The Early Kimmeridgian carbonate platform became separated into tectonic blocks showing diversified subsidence and displaying highly variable successions of deposits: these deposits were generally of marly-siliciclastic character commonly with *Nanogyra* coquina interbeds, correlated with the limestone-marly-coquina formation of Dembowska (1979). The changing marine conditions were controlled by local depositional-erosional processes. Such a development is displayed by the Nidzica Member, the origin of which was possibly attributed to some processes of uplift, tilting and erosion at the former marginal zone of the carbonate platform in north-eastern Poland. It is represented by thin, lithologically strongly contrasted deposits showing stratigraphical discontinuitites and a marked stratigraphical range from the upper part of the Lower Kimmeridgian (upper Hypselocyclum to Divisum zones) to some lower parts of the Upper Kimmeridgian, with a possible larger stratigraphical gap at the top in some sections. The coeval deposits in other areas showed marked differences in development generally related to strongly contrasted subsidence: in the Holy Cross Mountains in central Poland where the thick units of marly-limestone deposits of the Coquina (or Stobnica Coquina) Formation were deposited (*e.g.*, Wierzbowski, 2023), but also in other European areas, including the Banné Member of the lower Reuchenette Formation in northern Switzerland (*e.g.*, Jank *et al.*, 2006a, b).

6. The numerous Late Kimmeridgian ammonites of the Eudoxus Chron recorded already from the topmost deposits of the Coquina/Stobnica Coquina Formation, and from the directly overlying marls and shales of the Pałuki Formation include invasive Boreal-Subboreal forms (cardioceratids of the genus *Haplocardioceras*, and aulacostephanids of the subgenus *Aulacostephanoceras* – see *e.g.*, Kutek, 1961; Dembowska, 1965; Wierzbowski, Wierzbowski, 2019; cf. also Borrelli, 2014), occurring along with commonly encountered Submediterranean faunas, and indicative of an open marine deeper-water environment. Such a lithological and faunal succession has been commonly described from deeper parts of the basin ranging from the north-western margin of the Holy Cross Mts. in the south to the Kujawy area in the north (*e.g.*, Kutek, 1961; Dembowska, 1965; Matyja, Wierzbowski, 2014; Wierzbowski, 2023). The coeval deposits in more marginal parts of the basin, like that of the area of study, are more silty in character, and their succession is possibly less complete, with the possibility of the occurrence of larger stratigraphical gaps at their base. On the other hand, in some southern areas of the Holy Cross Mountains the occurrence of shallow-water oyster-terebratulid coquinas and cross-bedded bioclastic-sandy coquinas during the Eudoxus Chron has been interpreted as the final regressive segment of the tectono-stratigraphic LUK sequence and/or beginning of the new KVB sequence (Kutek, 1994a; see also Wierzbowski, 2023). Their origin resulted from the tectonic uplift in the south-western and north-eastern margins of the Holy Cross Mountains, the consequence of which was the local subsequent development of typical shallow-water carbonate platform deposits during the middle to late Eudoxus Chron of the Late Kimmeridgian (Gutowski, 1992, 1998; Wierzbowski, 2023).

7. The general subsidence over large areas of epicratonic Poland brought about the sedimentation of the clays and shales of the Pałuki Formation in a fairly deep environment, including sedimentation of the organic-rich shales of the amoeboceras horizon with common small-sized *Nannocardioceras* ammonites at the boundary between the Eudoxus to Autissiodorensis chrons of the Late Kimmeridgian. This stratigraphical interval can be compared with the shelf dysoxic-anoxic event system (SDAE, after Rogov *et al.*, 2020) which ranged from high-latitudes resembling very much the highly oxygen-restricted bottom conditions of some Kimmeridge Clay sediments from NW Europe. At the end of the Kimmeridgian stronger tectonic activity occurred which locally highly affected sedimentation, including the area of study where sudden changes in thickness of deposits have been observed.

8. The tectonic activity at the end of the Kimmeridgian – beginning of the Tithonian influenced markedly the development of the ammonite faunas. From the palaeogeographic point of view, the Autissiodorensis Chron of the latest Kimmeridgian in epicratonic Poland (and in northern Europe) was a time when provincialism of ammonite faunas became strongly pronounced (*e.g.*, Kutek, 1994a). It corresponded to the foundation of the new ammonite lineage leading from *Discosphinctoides*, having its roots in Submediterranean-Mediterranean areas, which migrated into areas of Poland possibly already during the Eudoxus Chron. The following evolutionary development of indigenous *Sarmatisphinctes* during the Autissiodorensis Chron in Poland and Russia marked a beginning of the lineage of successive members of Virgatitidae: *Ilowaiskya-Zaraiskites-Virgatites* typical of the Lower Tithonian of north-eastern Europe (*e.g.*, Kutek, Zeiss, 1997; see also Rogov, 2010; Enay, Howarth, 2019). This evolutionary development was a consequence of the palaeogeographic separation of the Polish basin with regards to the Tethyan and north-western epicratonic areas of Europe beginning from the latest Kimmeridgian. The barrier successively came into existence in the south as the belt of carbonate shoals of the Štramberk facies (Kutek, 1994a). The relevant data from north-western Poland – Western Pomerania – revealed also marked tectonic uplifts during the Late Kimmeridgian and the Early Tithonian (*e.g.*, Wilczyński, 1962; see also Bembenek *et al.*, 2021 including unpublished materials of B.A. Matyja and M. Barski). This is also the case in the sedimentation of the Żnin Member of northern Poland pointing to a regressive episode during the earliest Tithonian. The following tectonic activity in the north-west – in Poland and other European areas – at the end of the Early Tithonian opened temporarily a new sea route, however, which resulted in a short migration into the area of north-western and central Poland of the North-West-European representatives of the subfamily Pavloviinae (*Pavlovia*, *Virgatopavlovia*) (Matyja, Wierzbowski, 2016; *cf.* also Wilczyński, 1962).

9. The succession of marly deposits with common detrital siliciclastic material as recognized from the base of the Tithonian, up to the boundary beds with the Upper Tithonian (including thus the uppermost part of the Pałuki Formation), and the following succession of the shallow-water carbonates of the Kcynia Formation, may be interpreted as resulting from the long-time climatic changes, although with some superimposed effects of local synsedimentary tectonic activity. The final episode which continued the long-term marine regression culminated in the deposition of the brackish Purbeckian-type facies including the evaporitic deposits of the Wieniec Member, currently assigned to the lowermost Cretaceous. The sedimentation of all these deposits corresponded possibly to a 2.4 myr cycle: including two half cycles – more humid and more arid ones, respectively, each of them about 1.2 myr (Grabowski *et al.*, 2021).

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Appendix

SYSTEMATIC PALAEONTOLOGY

The comments given below refer to the selected ammonite specimens illustrated herein. They are coming from several boreholes discussed in the study: Nidzica IG 1, Olsztyn IG 1, Lipno 1, Żuromin 1, Żuromin 5, and Sierpc 1, and include representatives of the families Aulacostephanidae, Ataxioceratidae and Virgatitidae, important for stratigraphical interpretations, especially of the Lower Kimmeridgian, and the uppermost Kimmeridgian – Lower Tithonian intervals. The specimens mostly have not been illustrated so far, although they have been used commonly by many authors (*e.g.*, Dembowska, 1970, 1973, 1983; Kutek *et al*., 1973; Dembowska, Malinowska, 1977; Niemczycka, 1983) in their assessments of the stratigraphical interpretations of the Kimmeridgian and Tithonian deposits in the studied area. All the specimens are housed at the Museum of the Polish Geological Institute – National Research Institute in Warszawa (collections number II: 797, 979, 984, 999, 1037).

The following abbreviations are used herein in the description of ammonites: D – diameter of specimen in mm; Wh – whorl height as a percentage of D; Ud – umbilical diameter as a percentage of D; PR – number of primary ribs per whorl (or PR/2 per half a whorl), SR/PR – secondary/primary rib ratio counted on 5 primary ribs at given diameter.

FAMILY AULACOSTEPHANIDAE SPATH, 1924

The only specimen from the lowermost Kimmeridgian found in the coral formation of Nidzica IG 1 borehole at 1260 m (Pl. 1: 1) is a fragment of the body-chamber with a final part of the phragmocone (D = 50 mm, Wh = 44, Ud = 16, PR/2 = 15, SR/PR = 2.4). It is very close to *Vineta submediteranea* (Wierzbowski), and especially to its older variety from the Bimammatum Zone – lower Planula Zone (*e.g.*, Wierzbowski, 1978, pl. 3: 1–3; Wierzbowski *et al.*, 2010, pl. 7: 1, 2; see also Malinowska, 1991, pl. 11: 21, where the specimen discussed was illustrated).

Another fragmentarily preserved specimen (Pl. 1: 7) from Sierpc 1 borehole (1424.6 m) mentioned *e.g.*, by Niemczycka (1983, p. 277, fig. 2) as "*Ataxioceras* sp." came from the limestone-marly-coquina formation. It represents a part of the phragmocone showing the strongly developed and regularly-spaced long blunt outer ribs, and the weaker, somewhat obliterated in the middle of the whorl, rather distant primary ribs. The specimen is strongly involute (Ud = 23), and it represents most possibly the genus *Involuticeras*. The fragmentarily preserved small specimen from the same borehole at 1418.5 m (Pl. 2: 5) is a part of a whorl showing short protruding primary ribs and well-developed secondary ribs (SR/PR equals about 3–4) with a smooth narrow groove on the ventral side: it belongs to *Aulacostephanus*, being somewhat similar to *A. peregrinus* Ziegler; the specimen was originally referred to as "?*Rasenia* sp." (see *e.g.*, Niemczycka, 1983, fig. 2).

A very characteristic specimen from Olsztyn IG 1 borehole at 909.5 m coming from the Łyna Formation is small but possibly fully-grown (Pl. 1: 4). It is 25 mm in diameter, densely-ribbed in the innermost whorls, but revealing more distant primary ribs on the outer whorl (PR/2 = 12 at D = 25 mm). The secondary ribs are numerous (SR = 3.4) on the outer whorl, and the ornamentation is heavily disturbed here by the deep, collared constrictions bordered by the flared ribs. The specimen is closely related to *Pictonia* (*Pictonia*) being especially close to *Pictonia normandiana* Tornquist although showing a much smaller size. It resembles markedly the small-sized form referred to as *Pictonia* (*Pictonia*) aff. *normandiana* Tornquist from the Planula Zone of the Wieluń Upland, central Poland (Matyja, Wierzbowski, 1997, pl. 5: 5; see also Wierzbowski, 2022, p. 70, pl. 2: 5).

Two specimens of *Prorasenia* from the Łyna Formation in Olsztyn IG 1 borehole, at 985.7 and 982.2 m (Pl. 1: 2, 3), show the swollen triplicate ribs in the inner whorls, and the biplicate ribs on the outer whorl which are the common features of the genus. The coiling is weakly involute to weakly evolute, the ornamentation consists of coarse ribs (at D = 18 mm, PR = 20 in smaller specimen from 982.2 m; at D = 30 mm, PR = 24 in larger specimen from 985.7 m). The specimens, although fragmentarily preserved, can be compared with *Prorasenia bathyschista* (Koerner) known mostly from the Planula Zone (Matyja, Wierzbowski, 1997; Wierzbowski *et al.*, 2010).

Specimens of the genus *Aulacostephanus* occur fairly commonly in the uppermost Kimmeridgian part of the Pałuki Formation in all the studied boreholes. Of special stratigraphical importance are those from the topmost part of the formation in the Lipno 1 borehole the systematical status of which is revised herein (see also above). The largest specimen from 1520 m (Pl. 2: 1) attaining over 120–140 mm in diameter (its final size exceeds the diameter of the core) was originally referred to as "*Aulacostephanus* cf. *pseudomutabilis* (Loriol)" (*e.g.*, Niemczycka, 1983). The specimen is moderately densely ribbed (PR = 27, SR/PR = 4.4 at D = 86 mm), and shows very weakly involute coiling (at D = 86 mm, Wh = 37, Ud = 35). The primary ribs are very coarse, and short, they split very low on the whorl side into strongly prorsiradiate secondaries. Both the large size of the specimen, and the character of its ornamentation and type of coiling markedly indicate that it belongs, however, to *Aulacostephanus autissiodorensis* (Cotteau) (see *e.g.*, Ziegler, 1962).

Another *Aulacostephanus* specimen from 1523.3 m in Lipno 1 borehole (Pl. 2: 3) was originally interpreted (*e.g.*, Niemczycka, 1983) as "*Aulacostephanus* cf. *eudoxus* (d'Orbigny)/*A. eudoxus elegans.* Ziegler." This is a small-sized specimen (D = 35 mm, Wh = 37, Ud = 28) having distant primary ribs, and sparsely placed secondary ribs which are strongly accentuated at the transition to the ventral side of whorl (PR/2 = 7, SR/PR = 2.5). It represents mostly the phragmocone with an initial part of the body chamber at 32 mm diameter. The character of ribbing strongly suggests a close affinity to *Aulacostephanus undorae* (Pavlov).

FAMILY ATAXIOCERATIDAE BUCKMAN, 1921

The specimen of *Subnebrodites* newly discovered in the collection comes from the Łyna Formation of the Olsztyn IG 1 borehole, at 909.3 m (Pl. 1: 5). This unique specimen shows the weakly involute coiling (D = 45 mm, Wh = 36, Ud = 34) and typical ornamentation of the genus consisting of the biplicate and single, markedly prorsiradiate ribs (PR = 30 at D = 45), which became weaker at the ventral side; the peristome is, however, not preserved (the specimen represents the phragmocone with a part of the body chamber) which precludes its macro- or microconch affiliation: *Subnebrodites planula* (Hehl in Zieten) *versus S. laxevolutum* (Fontannes). This ammonite biospecies corresponding to *S. planula* recently discussed by Schweigert and Kuschel (2017) is diagnostic of the Planula Subzone or horizon in the middle part of the Planula Zone of the lowermost Kimmeridgian.

Possibly the most commonly cited specimen from the limestone-marly-coquina (V) formation was that from the Żuromin 5 borehole at 1416.5 m (Pl. 1: 6): it was commonly referred to as "*Ataxioceras* sp." (*e.g.*, Niemczycka, 1983, p. 277, fig. 4), sometimes as "? *Ataxioceras* sp." (Malinowska, 1988, p. 51, tab. 2) or even treated as difficult for closer identification (Kutek *et al*., 1973). This stratigraphically important, although poorly preserved specimen, is represented by a quarter of the whorl showing fairly irregular ribbing. The fairly long primary ribs show biplicate, polygyrate and even polyplocoid subdivision into secondary ribs, somewhat disturbed by commonly occurring constrictions. The character of ornamentation and the evolute coiling strongly suggest its close relation to *Ataxioceras* (*Parataxioceras*) of the Hypselocyclum Zone (see *e.g.*, Atrops, 1982).

Two fragmentarily preserved specimens showing very dense ribbing consisting of single and biplicate prorsiradiate ribs, and involute coiling, come from the uppermost part of the limestone-marly-coquina formation (borehole Żuromin 1 at 1416.5 m; Pl. 1: 8), and the lowermost part of the Pałuki Formation (borehole Nidzica IG 1 at 1101.7 m; Pl. 1: 9). The ribs split at about half of the whorl height (PR/2 = 20 at D = 60 mm, Wh = 50, Ud = 22 in the specimen from the Nidzica IG 1 borehole). The specimens represent possibly the genus *Discosphinctoides* Olóriz, 1978 which is sometimes treated as a younger synonym of *Lithacoceras* as interpreted by Enay and Howarth (2019), but see also *e.g.* Főzy *et al*. (2022) who did not support such a wide treatment of the genus *Lithacoceras* and claimed for separate recognition of the genus *Discosphinctoides* commonly represented in the Upper Kimmeridgian *e.g*., in southern Germany.

FAMILY VIRGATITIDAE SPATH, 1923

Ammonites of the genus *Sarmatisphinctes* occurring at the base of the family lineage are commonly encountered in the part of the Pałuki Formation corresponding to the Autissiodorensis Zone of the uppermost Kimmeridgian, in all the boreholes studied. They are represented by a number of species/subspecies of the genus (see *e.g*., Kutek, Zeiss, 1997; Rogov, 2010), including especially *S. subborealis* (Kutek et Zeiss) and *S. fallax* (Ilovaisky). The former is *e.g.*, well represented in Lipno 1 where a large specimen (Pl. 2: 4), possibly attaining at least about 120 mm in diameter, was found at 1523.8 (see Niemczycka, 1983). It shows the characteristic features of the species such as the occurrence mostly of biplicate ribs, all of them showing a fairly low located point of rib division. It compares well with large specimens of *S. subborealis* as illustrated by Kutek and Zeiss (1997, pls. 16–18). Another smaller specimen of that species illustrated herein comes from the Nidzica IG 1 borehole at 1068.9 m (Pl. 2: 6). It is about 60 mm in diameter and shows fairly dense ribbing of the inner whorls, and more distant of the outer whorl (PR = 33): the ribs are mostly biplicate, and occasionally triplicate; possibly a part of the final peristome is preserved suggesting the specimen is a microconch. It resembles very much the specimens of *S. subborealis* differing in appearance of some triplicate ribs, and a somewhat higher point of rib division; it resembles *S. zeissi* Rogov treated herein as the subspecies of *S. subborealis* (*cf.* Rogov, 2010).

The specimen of *Sarmatisphinctes* from Nidzica IG 1 at 1066.4 m (Pl. 2: 2) shows very dense mostly biplicate ribbing, but with some single and triplicate ribs up to about 50 mm diameter (PR = 40), disturbed by commonly occurring constrictions. The point of rib furcation is strongly variable, and although most commonly placed at the middle of the whorls, it may be located also in the lower part of the whorl. The specimen can be possibly accommodated in *Sarmatisphinctes fallax*, but it is possibly close to *S. ilowaiskii* Rogov, treated herein as a subspecies of the former.

The specimen from Nidzica IG 1 borehole at 1065.6 m (Pl. 3: 1) is fairly large and shows the evolute coiling (D = 97 mm, Wh = 34, Ud = 40) with moderately-densely placed biplicate and triplicate ribs on the outer whorl (PR = 37). The primary ribs are prorsiradiate, whereas the secondaries appearing at about half of the whorl show a rectiradiate course. The specimen is closely comparable to *Ilowaiskya klimovi* (Ilovaisky) (*cf. e.g.*, specimens illustrated by Mikhailov, 1964; and Kutek, Zeiss, 1997), and as such has been treated by Dembowska (1973, p. 14). Still younger specimens of *Ilowaiskya* coming from Nidzica IG 1 borehole at 1065.2 m include two specimens (Pl. 3: 2, 3) attributed to *I. pseudoscythica* (Ilovaisky) (see also Dembowska, 1973): they show commonly densely-ribbed inner whorls with biplicate ribs, followed by bi- and triplicate ribs on the outer whorls, and some reveal polygyrate subdivision, similarly as described so far in other representatives of the species (*cf.* Mikhailov, 1964; Kutek, Zeiss, 1997).

The youngest Jurassic ammonites occurring directly above the *Ilowaiskya* ammonites from the topmost part of the Pałuki Formation in Nidzica IG 1 borehole at 1063.5 m (Pl. 3: 4, 5) are represented by fragments of whorls. They show fairly dense ribbing with the commonly occurring virgatotome subdivision typical of the genus *Zaraiskites*. The specimens show rather distant virgatotome ribbing which is fairly regular with maximally up to four secondaries per one primary rib which strongly suggests their relation to *Zaraiskites scythicus* (Vischniakoff) (see Kutek, Zeiss, 1974; Kutek 1994b).

LITHOSTRATIGRAPHY – DESCRIPTION OF THE NEW MEMBER

NIDZICA MEMBER

Lithostratigraphical position and history. The deposits of the new member were interpreted originally as “the Lower Kimmeridgian” of the northern part of the Płock Trough characterized by a marked share of silty to sandy interbeds, and of small thickness of the whole section (*e.g.*, Dembowska, 1962, 1970). These deposits were successively included into the limestone-marly-coquina (V) formation of Dembowska (1979) and compared with reservation to the Raducz (Raduckie) Member as based on the Raducz IG 1 borehole section in the southern part of the Płock Trough (see Dembowska, 1979, 1986). The latter shows, however, much larger thickness and different lithology from these of the newly distinguished Member (see above, herein). The newly distinguished Nidzica Member is treated as the lateral counterpart of the whole limestone-marly-coquina (V) formation = Coquina Formation = Stobnica Coquina Formation (*cf. e.g.*, Dembowska, 1979; Kutek, 1994a; Matyja, Wierzbowski, 2014). It shows, however, a marked attenuation of the succession when compared with “normal” full development of the formation which possibly is a response to the special sedimentary conditions (including the episodes of non-deposition) affecting the new Member (see details comments in the text herein).

Name and type section. After Nidzica town in north-eastern Poland (Warmia and Mazury district – Polish: *województwo warmińsko-mazurskie*) where the deposits of the Member were penetrated by the fully-cored Nidzica IG 1 borehole (Polish name: *ogniwo z Nidzicy*) which is treated as the type-section of the unit (1114.9–1101.8 m). The core is preserved in the core-store of the Polish Geological Institute – National Research Institute at Iwiczna near Warszawa.

Type area and reference sections. Northern part of the Płock Trough where the deposits of the Member were encountered in several boreholes: *e.g.*, Żuromin (Żuromin 1 and 5), and Lipno (Lipno 1, 2 and 4), as discussed herein.

Thickness. Generally small, from 13 m (Nidzica IG 1) to about 24–25 m (Żuromin 1 and 5).

Lithology. Very variable, from detrital glauconitic sandy bioclastic limestones and oolitic limestones to marly siltstones and fine-grained sandstones with intercalations of fine-grained bioclastic coquina with *Nanogyra* shells, with interbeds of clay and shale, commonly encountered at the base of the unit (see Wierzbowski H., Wierzbowski A., in press).

Boundaries. Lower boundary with the oolitic formation (V) of Dembowska (1979) at the top of the oolitic and micritic limestones; upper boundary with the overlaying marls, sometimes also marly siltstones with abundant ammonites of the Pałuki Formation (= shale-marly-siltstone (VI) formation) of Dembowska (1979).

Geological age. The ammonites found in the cores generally are indicative of the upper part of the Lower Kimmeridgian (Hypselocyclum to Divisum zones), and possibly some lowest parts of the Upper Kimmeridgian (see *e.g.*, Dembowska, 1970, 1983; Niemczycka, 1983; see also descriptions of ammonites herein; see Figs. 2–4). The overlying Pałuki Formation, occurring directly above the Nidzica Member, yielded ammonites of the Eudoxus Zone of the Upper Kimmeridgian.

Distribution and equivalents. The Member is characteristic of the northern part of the Płock Trough. It is successively replaced towards the south by limestones and marls with intercalations of *Nanogyra* shellbeds; such a transitional character is shown, *e.g.*, by deposits in the Sierpc 1 and Kamionki 1 and 2 boreholes where some interbeds of siltstones still occur, but the total thickness is larger (35.5 to 43 m).

Plates

PLATE 1

Lower and Upper Kimmeridgian ammonites of the families Aulacostephanidae and Ataxioceratidae

Fig. 1. *Vineta* cf. *submediteranea* (Wierzbowski); Nidzica IG 1, 1260 m; 797.II.222

Fig. 2. *Prorasenia* cf. *bathyschista* (Koerner); Olsztyn 1G 1, 985.7 m; 999.II.171

Fig. 3. *Prorasenia* cf. *bathyschista* (Koerner); Olsztyn IG 1, 982.2 m; 999.II.161

Fig. 4. *Pictonia* (*Pictonia*) aff. *normandiana* Tornquist; Olsztyn IG 1, 909.5 m; 999.II.101

Fig. 5. *Subnebrodites planula* (Hehl in Zieten) – *laxevolutum* (Fontannes); Olsztyn IG 1, 909.3 m; 999.II.100

Fig. 6. *Ataxioceras* (*Parataxioceras*) sp.; fragment of the body-chamber; Żuromin 5, 1416.5 m; 1037.II.11

Fig. 7. *Involuticeras* sp.; phragmocone; Sierpc 1, 1424.6 m; 984.II.69

Fig. 8. *Discosphinctoides* sp.,; Żuromin 1, 1416.5 m; 979.II.107

Fig. 9. *Discosphinctoides* sp.; Nidzica IG 1, 1101.7 m; 797.II.187

The phragmocone/body chamber boundary is arrowed

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PLATE 2

Upper Kimmeridgian ammonites of the families Aulacostephanidae and Virgatitidae

Fig. 1. *Aulacostephanus autissiodorensis* (Cotteau); the phragmocone/body chamber boundary runs possibly within a missing part of the outer whorl; Lipno 1, 1520 m; 979.II.166

Fig. 2. *Sarmatisphinctes fallax ilowaiskii* Rogov; the phragmocone/body chamber boundary runs possibly within a missing part of the outer whorl; Nidzica IG 1, 1066.4 m; 797.II.50

Fig. 3. *Aulacostephanus undorae* (Pavlov); Lipno 1, 1523.3 m; 979.II.168

Fig. 4. *Sarmatisphinctes subborealis subborealis* (Kutek et Zeiss); Lipno 1, 1523.8 m; 979.II.169

Fig. 5. *Aulacostephanus* sp.; Sierpc 1, 1418.5 m; 984.II.67

Fig. 6. *Sarmatisphinctes subborealis zeissi* Rogov; Nidzica IG 1, 1068.9 m; 797.II.85

The phragmocone/body chamber boundary is arrowed

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PLATE 3

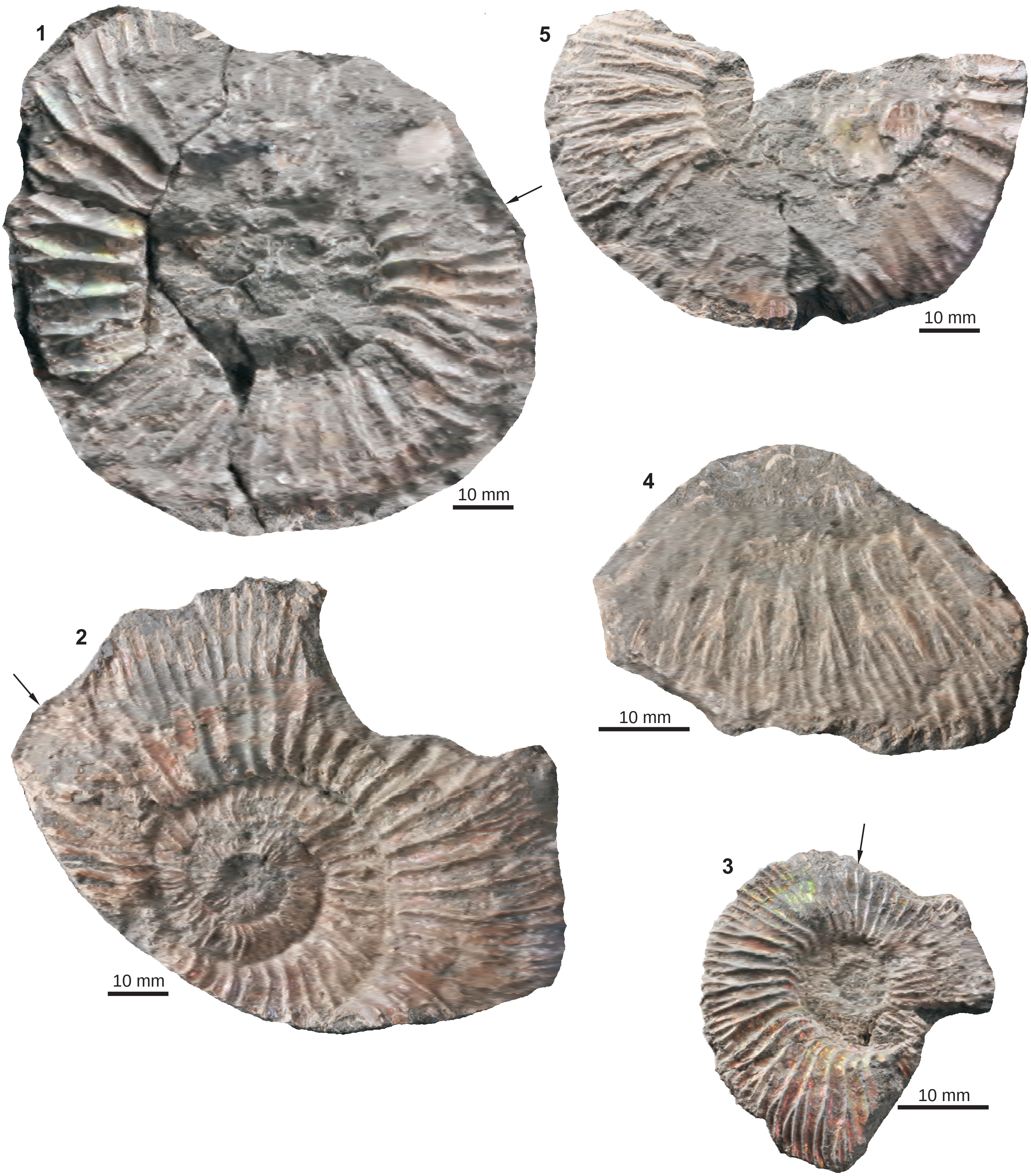
Lower Tithonian ammonites of the family Virgatitidae

Fig. 1. *Ilowaiskya klimovi* (Ilovaisky); Nidzica IG 1, 1065.6 m; 797.II.32

Fig. 2, 3. *Ilowaiskya pseudoscythica* (Ilovaisky); Nidzica IG 1, 1065.2 m; 797.II.25 and 797.II.26

Fig. 4, 5. *Zaraiskites* cf. *scythicus* (Vischniakoff); Nidzica IG 1, 1063.5 m; 797.II.7 and 797.II.8

The phragmocone/body chamber boundary is arrowed



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