

Foraminiferal biostratigraphy of the Middle and Upper Jurassic of the Polish Lowlands: the state of the art

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The foraminifera-based biostratigraphy of the Middle and Upper Jurassic of the Polish Lowlands was re-evaluated. Biostratigraphic charts providing ranges of the most important foraminiferal taxa characteristic of individual Jurassic stages are presented in relation to the currently used ammonite-based standard stratigraphic divisions. The study contains the new research on the foraminifera fauna and includes earlier results available in published and archival reports. In the Oxfordian and Lower Kimmeridgian deposits, various foraminiferal assemblages were distinguished with reference to the lithofacies in the individual parts of the Polish Basin and varying influences of the palaeogeographical provinces. Additionally, the foraminiferal zones in the Oxfordian and Lower Kimmeridgian deposits of southeastern Poland are distinguished based on detail study of foraminifers.

Key words: foraminifers, biostratigraphy, Middle and Upper Jurassic, Polish Lowlands.

INTRODUCTION

Middle and Upper Jurassic foraminifers from the Polish Lowlands have been studied for years. First data were obtained from natural outcrops in the Kraków–Wieluń Upland (e.g., [Wiśniowski, 1890](#); [Pazdro, 1954, 1958](#); [Bielecka, 1956](#)). Then, borehole data became available from the remaining area of the Polish Lowlands. [Bielecka and Pożaryski \(1954\)](#) established the first stratigraphic zonation for the Upper Jurassic of central Poland, based on microfossils. Upper Jurassic foraminiferal stratigraphy from the Chrzanów area was published by [Bielecka \(1960a\)](#). Subsequently, the base for establishing the foraminiferal biostratigraphy was the presence of numerous foraminiferal assemblages and their variability in the vertical profiles.

Synthetic contributions on the Jurassic of the Polish Lowlands on the basis of foraminiferal stratigraphy were published by [Malinowska \(1980, 1988\)](#) and [Marek and Pajchłowa \(1997\)](#). In those papers, as well as in many earlier micropalaeontological works, the stratigraphic position and the ranges of the most important foraminiferal taxa was presented against the background of various regional biostratigraphic divisions, which in many cases deviate from the European standard zonations.

The aim of the paper is to present stratigraphically important foraminiferal taxa occurring in the Middle and Upper Jurassic of the Polish Lowlands, with references to the standard ammonite divisions. In contrast to previously used divisions, the standard stages and substages applied in this publication and detailed correlation of the positions of biostratigraphic and chronostratigraphic boundaries allow using the foraminiferal data for broader, interregional correlations.

MATERIAL AND METHODS

All specimens described come from the archival collections of the PGI-NRI Geological Museum: W. Bielecka, 1954; 1960; 1981; W. Bielecka and O. Styk, 1980; 1981; J. Smoleń, 1998; 2000; 2011; 2012; 2015; J. Kopik from the Borucice1/C borehole, 1956, and collections of J. Smoleń from the boreholes: Cieclocinek IG-2, 2007; Brześć Kujawski IG-1, IG-2, IG-3, 2008; Jamno IG-1, IG-2, IG-3, 2008; Grudziądz IG-1, 2011; Darżlubie IG-1, 2011; 1/1a, IG-3, IG-4; 2012; Gorzów Wielkopolski IG-1, 2014; Kętrzyn IG-1, IG2, 2014; Narol PIG-1, PIG-2, 2015 and Polik IG-1, 2016 ([Fig. 1](#)). One thousand specimens have been selected from the twenty-one collections analysed. Best-preserved 243 specimens have been photographed. SEM images have been performed in the Micro-Area Analysis Laboratory.

Stratigraphical range charts of foraminiferal taxa have been prepared with references to new data (e.g., [Smoleń, 2000, 2011a, 2012a](#); [Wierzbowski et al., 2015](#)). Archival and unpublished micropalaeontological reports have been analysed as well. The foraminifera species list can be found in [Ap-](#)

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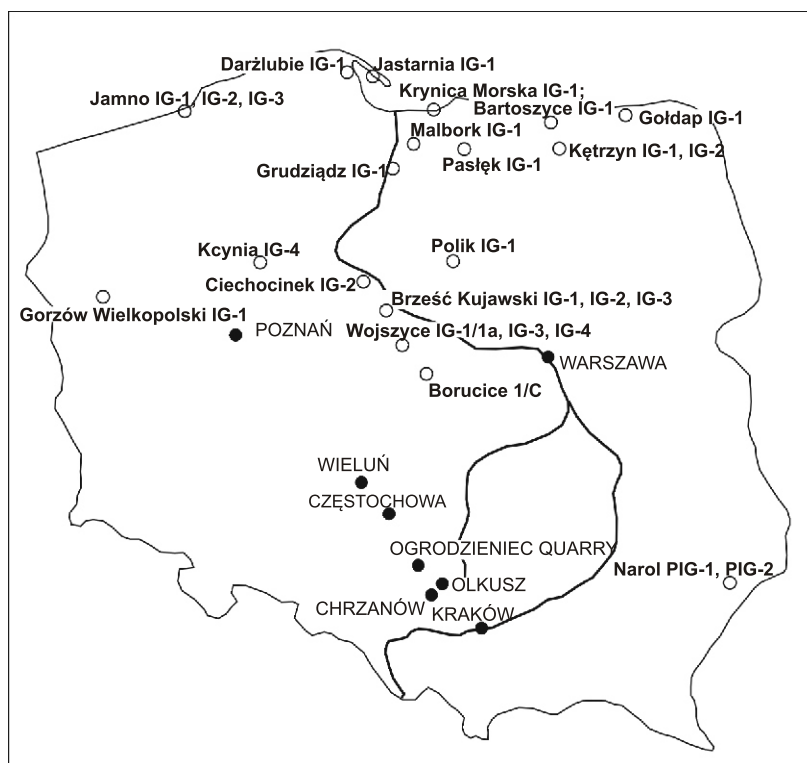


Fig. 1. Locations of boreholes that provided material used for this study

pendix 1*. The ammonite zonation applied have been based on Kopik (1998), Głowniak (2002, 2006a), Matyja and Wierzbowski (2000), Dembicz et al. (2006) and Wierzbowski et al. (2015, 2016).

MIDDLE JURASSIC

During the Middle Jurassic the area of Polish Lowlands was covered by an epicontinental sea (e.g., Marek and Pajchłowa, 1997). In the Aalenian, a narrow basin extended from the north-west to south-east in the present-day territory of Poland. The later transgressive impulses were the result of connections with the Tethys Ocean. The strong marine transgression covered almost the entire Polish Lowlands at the end of the Bathonian and towards the end of the Callovian. Middle Jurassic deposits developed as a sequence consisting of sandstones and clayey rocks, with carbonate-clastic facies dominant in the Upper Callovian. Middle Jurassic deposits of extra-Carpathian Poland contain diverse and multi-species foraminiferal assemblages that were subject to many micropalaeontological and biostratigraphic studies. These studies resulted in the identification of the characteristic foraminifera species and assemblages of the individual Middle Jurassic chronostratigraphic units. Composite charts of the ranges of important foraminifera species, correlated with the ammonite stratigraphy, are presented by Bielecka et al. (1980), Dayczak-Calikowska and Marcinkiewicz (1997), and Kopik and Marcinkiewicz (1997). In these publications, like in many other published and archival works, a subdivision into ammonite zones (providing regional ammonite zones based on local ranges of ammonites) was used for the Middle Jurassic deposits of the Polish Lowlands (Dayczak-Calikowska and Kopik, 1973), based on the scheme

by Różycki (1953). The Submediterranean standard zonal scheme (with minor modification) was applied first by Kopik (1998: table 3) who correlated it with local biostratigraphic schemes used previously in Poland. He correlated the Lower Kuiavian and large part of the Middle Kuiavian with the Upper Bajocian standard substage, and the uppermost part of the Middle Kuiavian (Schloenbachii Zone) and the Upper Kuiavian with the Bathonian standard stage (Fig. 2).

AALENIAN

The Lower Aalenian is represented in the Polish Lowlands by sandy-muddy deposits (e.g., Dayczak-Calikowska, 1997; Feldman-Olszewska, 1997). Marine facies of central Poland contain scarce agglutinated foraminifers. The Upper Aalenian is better documented by foraminifera fauna by Bielecka and Styk (1981a) and Kopik (1956). In clay-muddy deposits, starting from the Murchisonae Zone, foraminiferal assemblages are represented by abundant agglutinated foraminifera and few foraminifer specimens with calcareous tests, which appear for the first time in the Aalenian deposits of the Polish Lowlands. The stratigraphically important Upper Aalenian species include the following taxa: *Reinholdella dreheri* (Bartenstein) (Fig. 3C1, C2), *Verneuilinoides liasina* (Terquem et Berthelin) (Fig. 3B), *Ammodiscus glumaceus* Gerke et Sossipatrova (Fig. 3A), *Astacolus varians rectus* Franke, *A. reticulatus* (Schwager) (Fig. 3E) *Trochamminoides proteus* (Karrer) (Fig. 3D), *Lagenammina difflugiformis* (Brady) (Fig. 3H) and *Recurvoides trochamminiforme* Höglund (Fig. 3G), *Trochammina canningensis* Tappan (Fig. 3I, J) and *Haplophragmopides complanatus* Mjatliuk (Fig. 3L) which are rarely found from Discites to Humpresianum zones (Fig. 4).

* Supplementary data associated with this article can be found, in the online version, at doi: 10.7306/gq.1406

Standard ammonite zones and subzones			Ammonite zones and subzones (Kopik, 1998)			Ammonite zones and subzones (Dayczak-Calikowska and Kopik, 1973)					
OXF.	Mariae		OXF.	Mariae		OXF.	Mariae				
CALLOVIAN	UPPER	Lamberti	CALLOVIAN	UPPER	Lamberti	CALLOVIAN	UPPER	Lamberti			
		Athleta			Athleta			Duncani			
		Coronatum			Coronatum			Pollux			
	MIDDLE	Jason	CALLOVIAN	MIDDLE	Jason	CALLOVIAN	LOWER	Jason			
		Calloviense			Calloviense			Calloviense			
		Koenigi			Koenigi			Typicus			
		Herveyi			Herveyi						
BATHONIAN	UPPER	Discus	BATHONIAN	UPPER	Discus	BATHONIAN	UPPER	Discus			
		Retrocostatum			Orbis			Orbis	Paradoxus		
	MIDDLE	Bremeri	BATHONIAN	MIDDLE	Bremeri	BATHONIAN	MIDDLE	Bremeri			
		Morrisi			Morrisi			Morrisi			
		Subcontractus			Subcontractus			Procerites spp.			
	LOWER	Tenuiplicatus	BATHONIAN	LOWER	Tenuiplicatus	UPPER BAJOCIAN (KUJAW)	UPPER	Tenuiplicatus			
		Zigzag			Yeovilensis			Yeovilensis	Yeovilensis		
Macrescens					Macrescens			Compressa			
Convergens		Convergens			Convergens			Ferruginea			
BAJOCIAN	UPPER	Parkinsoni	BAJOCIAN	UPPER	Parkinsoni	UPPER BAJOCIAN (KUJAW)	MIDDLE	Parkinsoni			
									Bomfordi	Acris	Subarietis
									Densicostata		
	Garantiana	Tetragona	BAJOCIAN	UPPER	Tetragona	UPPER BAJOCIAN (KUJAW)	LOWER	Tetragona			
		Trauthi			Trauthi			Garantiana			
		Dichotoma			Dichotoma			Subfurcatum			
	Subfurcatum		Subfurcatum		Subfurcatum		Subfurcatum				
LOWER	Humphriesianum	Blagdeni	BAJOCIAN	LOWER	Humphriesianum	LOWER BAJOCIAN	MIDDLE	Blagdeni			
		Humphriesianum			Humphriesianum			Humphriesianum			
		Romani			Romani						
	Sauzei	Sauzei	Sauzei	Sauzei							
	Laeviscula		Laeviscula		Laeviscula		Sowerbyi				
	Discites		Discites		Discites		Discites				
AALENIAN	UPPER	Concavum	AALENIAN	UPPER	Concavum	AALENIAN	UPPER	Murchisonae			
		Murchisonae			Murchisonae			Murchisonae			
	Opalinum	Opalinum			Opalinum			Opalinum			

Fig. 2. Correlation of the zonal schemes (after Kopik, 1998, modified by Matyja and Wierzbowski, 2000)

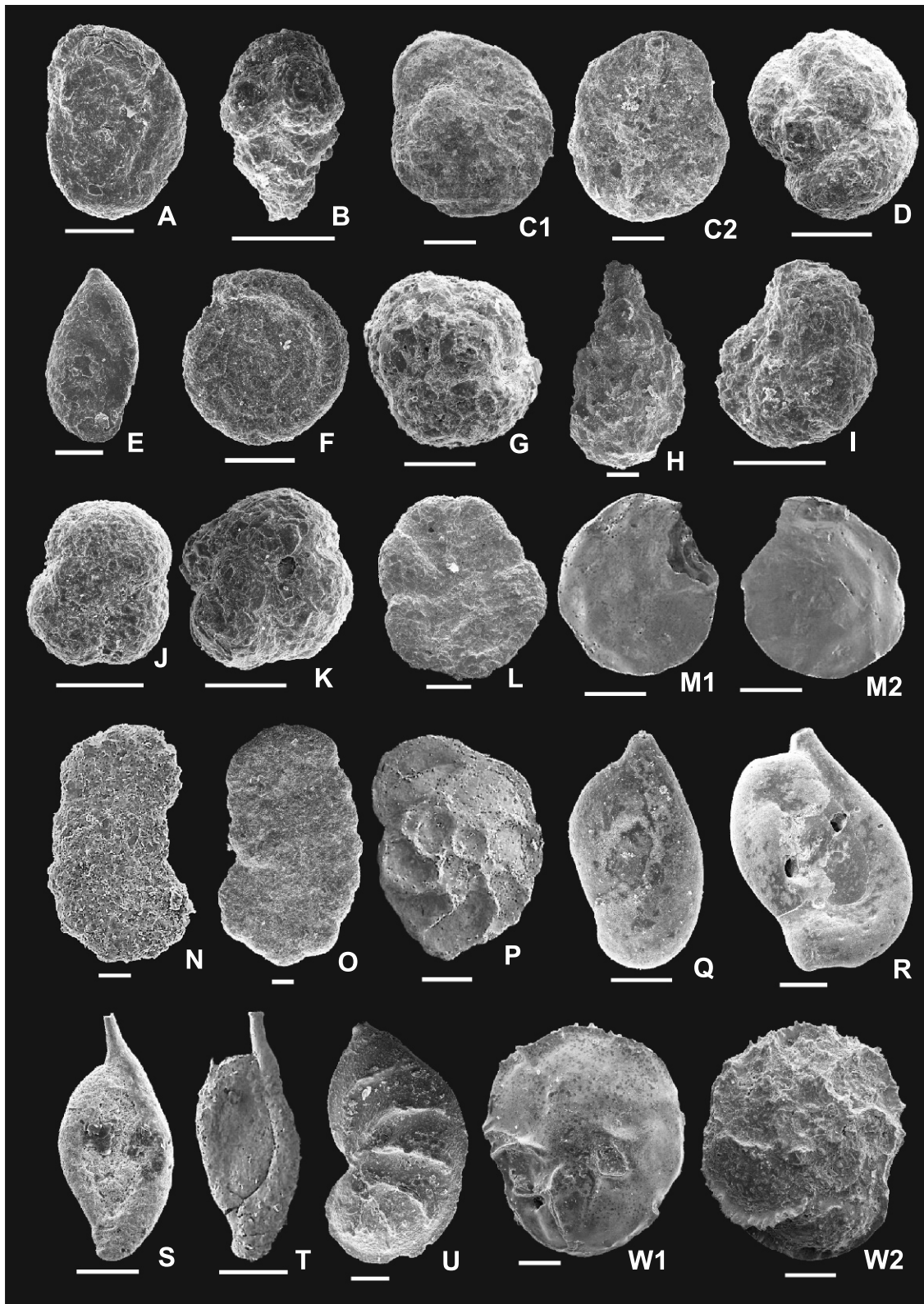


Fig. 3. Foraminifers from the Aalenian–Lower Bajocian (A–H) and Upper Bajocian (I–W2) deposits of the Polish Lowlands

A – *Ammodiscus glumaceus* (collection of Smoleń from the Brześć Kujawski IG-1, IG-2 and IG-3 boreholes, 2008); **B** – *Verneuilinoides liasina* (collection of Kopik, 1956); **C1** – *Reinholdella dreheri*, dorsal side (collection of Kopik, 1956); **C2** – *Reinholdella dreheri*, ventral side (collection of Kopik, 1956); **D** – *Trochamminoides proteus* (collection of Smoleń from the Brześć Kujawski IG-1, IG-2 and IG-3 boreholes, 2008); **E** – *Astacolus reticulatus* (collection of Kopik, 1956); **F** – *Ammodiscus orbis* (collection of Smoleń from the Brześć Kujawski IG-1, IG-2 and IG-3 boreholes, 2008); **G** – *Recurvooides trochamminiforme* (collection of Kopik, 1956); **H** – *Lagenammina difflugiformis* (collection of Kopik, 1956); **I, J** – *Trochammina canningensis* (collection of Kopik, 1956); **K** – *Recurvooides trochamminiforme* (collection of Kopik, 1956); **L** – *Haplophragmoides complanatus* (collection of Smoleń, 2011); **M1** – *Epistomina nuda*, ventral side (collection of Smoleń, 2011); **M2** – *Epistomina nuda*, dorsal side (collection of Smoleń, 2011); **N** – *Ammopalmula infrajurensis* (collection of Kopik, 1956); **O** – *Ammopalmula infrajurensis* (collection of Smoleń from the Wojszyce IG-1/1a, IG-3 and IG-4 boreholes, 2012); **P** – *Epistomina costifera* (collection of Smoleń from the Brześć Kujawski IG-1, IG-2 and IG-3 boreholes, 2008); **Q, R** – *Ophthalmidium carinatum terquemii* (collection of Smoleń, 2011); **S, T** – *Ophthalmidium carinatum agglutinans* (collection of Smoleń, 2011); **U** – *Lenticulina (Astacolus) interrumpa* (collection of Bielecka and Styk, 1980); **W1** – *Garantella ornata*, ventral side (collection of Bielecka and Styk, 1980); **W2** – *Garantella ornata*, dorsal side (collection of Bielecka and Styk, 1980); scale bars – 100 µm

AALE- NIAN	BAJOCIAN										BATHONIAN						STAGES						
	LOWER					UPPER					LOWER	MIDDLE	UPPER	SUBSTAGES									
	LOWER	UP- PER	UP- PER	UP- PER	UP- PER	Subfurcaum	Garantiana Dichotoma	Tetragona Trauthi	Parkin- soni Acris	Densicostata	Bomfordi	Convergens	Macrescens	Yeovilensis	Tenuiplicatus	Subcontractus	Morrisi	Bremeri	Retrocostatum	Discus	ZONES	Standard Submediterranean ammonite zonation	
																					Foraminifera		
																						<i>Ammodiscus glumaceus</i> Gerke et Sossipatrova	
																						<i>Verneuilinoides liasina</i> (Terquem et Berthelin)	
																						<i>Reinholdella dreheri</i> (Bartenstein)	
																						<i>Trochamminoides proteus</i> (Karrer)	
																						<i>Astacolus reticulatus</i> (Schwager)	
																						<i>Astacolus varians rectus</i> Franke	
																						<i>Ammodiscus orbis</i> Lalicker	
																						<i>Recurvoides trochamminiforme</i> Höglund	
																						<i>Lagenammina difflugiformis</i> (Brady)	
																						<i>Trochammina canningensis</i> Tappan	
																						<i>Haplophragmoides complanatus</i> Mjatluk	
																						<i>Verneuilinoides mauritii</i> (Terquem)	
																						<i>Ammobaculites fontinensis</i> (Terquem)	
																						<i>Epistomina costifera</i> Terquem	
																						<i>Ammopalmula infrajurensis</i> (Terquem)	
																						<i>Epistomina nuda</i> Terquem	
																						<i>Ophthalmidium carinatum agglutinans</i> Pazdro	
																						<i>Garantella ornata</i> (Hofker)	
																						<i>Lenticulina (Astacolus) interrupta</i> Blank	
																						<i>Ophthalmidium carinatum terquemi</i> Pazdro	
																						<i>Epistomina regularis</i> Terquem	
																						<i>Lenticulina mamillaris</i> (Terquem)	
																						<i>Planularia ex. gr. eugenii</i> (Terquem)	
																						<i>Lenticulina (Astacolus) volubilis</i> Dain	
																						<i>Lenticulina daphne</i> Bielecka et Styk	
																						<i>Ichtyolaria nympa</i> Kopik	
																						<i>Lenticulina (Planularia) polymorpha</i> (Terquem)	
																						<i>Lenticulina (Astacolus) kujaviana</i> Kopik	
																						<i>Lenticulina (Astacolus) polymorpha arachne</i> Kopik	
																						<i>Paalzowella pazdroe</i> Bielecka et Styk	
																						<i>Lenticulina (Astacolus) argonauta</i> Kopik	
																						<i>Spirillina radiata</i> Terquem	
																						<i>Reinholdella crebra</i> Pazdro	
																						<i>Palaeomiliolina czestochowiensis</i> (Pazdro)	
																						<i>Triplasia tricarinata</i> (Malecki)	
																						<i>Palaeomiliolina rawiensis</i> (Pazdro)	
																						<i>Geinitzinita nodosaria</i> (Terquem)	
																						<i>Verneuilinoides favus</i> (Bartenstein)	
																						<i>Epistomina coronata</i> Terquem	
																						<i>Lenticulina helios</i> (Terquem)	
																						<i>Trocholina conica</i> (Schlumberger)	
																						<i>Globuligerina bathoniana</i> (Pazdro)	
																						<i>Verneuilinoides witkowiensis</i> Bielecka et Styk	
																						<i>Paulina paula</i> (Pazdro)	
																						<i>Citharina clathrata</i> (Terquem)	
																						<i>Garantella sera</i> Pazdro	
																						<i>Nodosaria plicatilis</i> Wiśniowski	
																						<i>Ammovertella plicata</i> (Terquem)	
																						<i>Citharina heteropleura</i> (Terquem)	
																						<i>Epistomina mosquensis</i> Uhlig	
																						<i>Epistomina parastelligera</i> (Hofker)	
																						<i>Geinitzinita franconica franconica</i> (Gümbel)	

Fig. 4. Stratigraphic range charts of foraminifera species from the Aalenian and Bathonian deposits of the Polish Lowlands, ammonite zonation as used by Kopik (1998), Matyja and Wierzbowski (2000), Barski et al. (2004) and Dembicz et al. (2006)

BAJOCIAN

Lower Bajocian shallow-marine deposits, represented mainly by sandstones, mudstones and rare claystones, contain poor foraminiferal assemblages. In central Poland, there are few taxa, generally the same as those found in the Upper Aalenian (see Fig. 4). Detailed investigations of the Lower Bajocian sandy deposits (the Kościeliskie Beds), conducted between Częstochowa and Zawiercie, revealed also scarce microfauna (Kopik, 1998). Their lower part (the Kościeliskie sandstones) contains single agglutinated foraminifers. Larger foraminiferal assemblages have been found in the uppermost Lower Bajocian – Humphriesianum Zone, Blagdeni Subzone; Kopik, 1998).

Most of the foraminifera species, which continue from the Aalenian in the Polish Lowlands, have their last occurrences at the end of the Lower Bajocian. This is associated with a regressive event that started and continued during the early Late Bajocian (Dayczak-Calikowska, 1980). The lowermost Upper Bajocian (Subfurcatum Zone) of central Poland, represented by muddy-sandy facies, contains few foraminifera species. These include predominantly agglutinated and infrequent calcareous foraminifera, e.g.: *Ophthalmidium carinatum agglutinans* Pazdro, *Epistomina nuda* Terquem and *E. costifera* Terquem (Fig. 4; Bielecka and Styk, 1981a). Subsequent studies conducted in south-central Poland between Częstochowa and Zawiercie did not confirm the presence of Subfurcatum Zone deposits (Kopik, 1998).

Deposits of the Upper Bajocian Garantiana Zone record an onset of marine transgression and the sedimentary basin expansion. Throughout the Late Bajocian, the clay-muddy facies dominate a vast area of central Poland. A complex of claystones, mudstones and sandstones with siderites, referred to as the Częstochowa ore-bearing clays, was deposited in the Częstochowa–Zawiercie region (e.g., Leonowicz, 2013a, b, 2015). The Upper Bajocian deposits contain large foraminiferal assemblages, abundant in terms of the number of both species and specimens, described in papers by Pazdro (1954, 1958, 1969a), Bielecka and Styk (1969a, b, 1981a), Kopik (1956, 1969) and Smoleń (2008a, 2011a, 2012b, 2014a). In central Poland, the foraminifera fauna appears again in the Garantiana Zone, in which calcareous foraminifera become definitely predominant. The largest foraminiferal assemblages are known from the Parkinsoni Zone (equivalent of the Acris and Parkinsoni zones *sensu* Kopik, 1998). In the Częstochowa–Zawiercie region (south-central Poland), the first foraminifera appear later in the Parkinsoni Zone and the largest foraminiferal assemblages occur in the upper part of this zone (in the Acris and Parkinsoni zones *sensu* Kopik, 1998; Fig. 4).

The study of Kopik (1998) has also shown that some taxa such as *Reinholdella crebra* Pazdro and *Palaeomiliolina czestochowiensis* (Pazdro) (Fig. 4) known in central Poland only from the Bathonian onwards have their first occurrences in the uppermost Bajocian (Parkinsoni Zone *sensu* Kopik, 1998) in the Częstochowa region.

The analysis of studies carried out so far shows that diagnostic species in the Upper Bajocian deposits include: *Epistomina nuda* Terquem (Fig. 3M1, M2), *E. costifera* Terquem (Fig. 3P), *E. regularis* Terquem (Fig. 5A1, A2), *Ammopalmula infrajurensis* (Terquem) (Fig. 3N, O), *Garantella ornata* (Hofker) (Fig. 3W1, W2), *Ophthalmidium carinatum terquemi* Pazdro (Fig. 3Q, R), *O. carinatum agglutinans* Pazdro (Fig. 3S, T), *Lenticulina (Astacolus) interrumpa* Blank (Fig. 3U), *L. (A.) volubilis* Dain (Fig. 5C), *L. (A.) kujaviana* Kopik (Fig. 5F), *L. (A.) argonauta* (Kopik), *L. (A.) polymorpha arachne* Kopik (Fig. 5I, J), *L. (Planularia) polymorpha* (Terquem) (Fig. 5H), *L. daphne*

Bielecka et Styk (Fig. 5E), *Ichtyolaria nympha* Kopik (Fig. 5G), *L. mamillaris* (Terquem) (Fig. 5B) and *Planularia ex gr. eugenii* (Terquem) (Fig. 5D). Most of the foraminifera species, which have their first occurrences in the Upper Bajocian, range through the Lower Bathonian, or some through the Middle or even Upper Bathonian.

BATHONIAN

Over most of the Polish Lowlands, the Bathonian succession consists of clastic deposits represented by muddy-sandy and muddy-clayey facies with sideritic coquina layers, passing into sandstone facies. Such sedimentation type persisted until the end of the Bathonian in much of the Polish Lowlands, mainly in central and northwestern Poland. In south-central Poland (the region between Częstochowa and Zawiercie), clayey, muddy and sandy deposits with siderites were accumulated, referred to as the Częstochowa ore-bearing clay formation (Gedl and Kaim, 2012). The final stage of the deposition of these clays started in the Late Bathonian Retrocostarum Zone (Heterocostatus Subzone of the Orbis Zone *sensu* Kopik, 1998; Fig. 2). This zone contains also rare mudstones which are replaced by oolitic limestones (called the Częstochowa oolite). In many areas of the Kraków–Częstochowa Upland, the uppermost Upper Bathonian (Discus Zone) refers to an erosional hiatus (Kopik, 1998).

Like those of the Upper Bajocian, the Bathonian foraminifera form multi-species microfaunal associations. They have been well investigated and described from many boreholes, mainly in central and NW Poland (Bielecka and Styk, 1969a, b, 1981b; Kopik, 1969; Smoleń, 2007, 2008b, 2011b, c, 2012b, 2014a, b). The oldest contributions on Bathonian foraminifera concerned ore-bearing clays from the Kraków–Wieluń Upland (Pazdro, 1954, 1959, 1960, 1967, 1969a, b; Małecki, 1971; Garbowska et al., 1978). In the area between Częstochowa and Zawiercie, Kopik (1998) distinguished foraminiferal assemblages characteristic of the individual Bathonian substages.

Based on correlation with standard ammonite zones (after Maryja and Wierzbowski, 2000, 2003), the largest foraminiferal assemblages have been documented in strata containing continuous concretionary siderite horizons. Large and taxonomically diverse foraminiferal assemblages are found in the Lower Bathonian deposits of the Convergens and Macrescens subzones of the Zigzag Zone (Smoleń, 2011a). In the Middle Bathonian, such associations are present mainly in the Subcontractus and Morissi zones (Smoleń, 2004, 2006, 2012a).

Analysis of the above-mentioned previous studies has shown that the Lower Bathonian deposits contain most of the species that are found in the uppermost Upper Bajocian. The following species terminate their stratigraphic ranges in the Lower Bathonian (Tenuiplicatus Zone; Fig. 4): *Ammopalmula infrajurensis* (Terquem), *Garantella ornata* (Hofker), *Lenticulina (A.) interrumpa* Blank, *L. daphne* Bielecka and Styk, *Epistomina costifera* Terquem and *Ichtyolaria nympha* Kopik. There is also the upper limit of the continuous range of *Ophthalmidium carinatum terquemi* Pazdro, and an increase in the quantitative contribution of *O. carinatum agglutinans* Pazdro, *Epistomina regularis* Terquem, *E. nuda* Terquem, *Palaeomiliolina czestochowiensis* (Pazdro), *Planularia ex gr. eugenii* (Terquem) and *Lenticulina (A.) volubilis* Dain. The new species, that have their first occurrences in the Lower Bathonian (Fig. 4), include *Paulina paula* Pazdro, *Triplasia tricarinata* (Małecki) (Fig. 5T), *Verneuilinoides favus* (Bartenstein) (Fig. 5S), *Epistomina coronata* Terquem (Fig. 5Y), *Geinitzinita nodosaria*

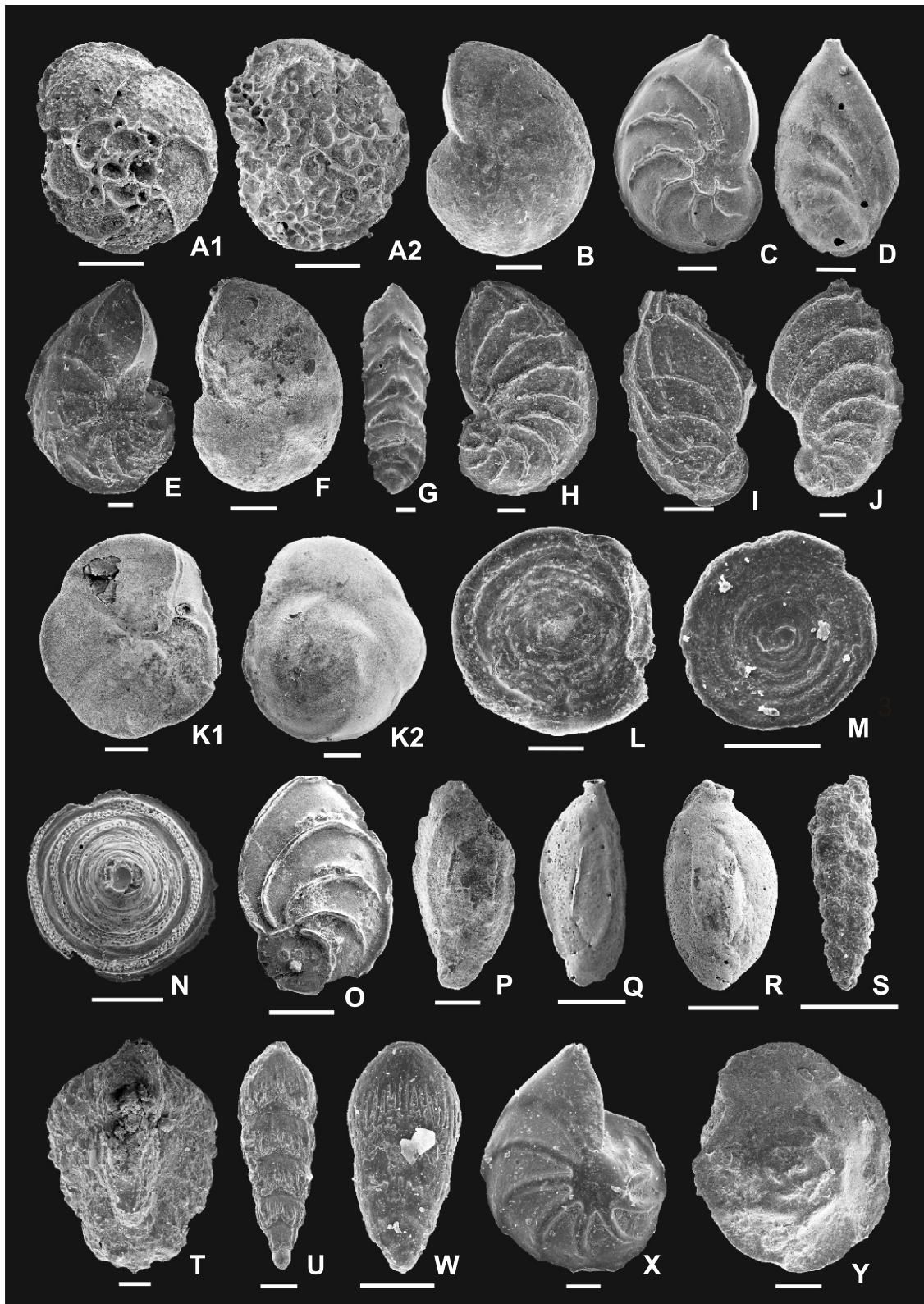


Fig. 5. Foraminifers from the Upper Bajocian (A1–J) and Lower and Middle Bathonian (K1–Y) deposits of the Polish Lowlands

A1 – *Epistomina regularis*, dorsal side (collection of Smoleń, 2012); A2 – *Epistomina regularis*, ventral side (collection of Smoleń, 2012); B – *Lenticulina mamillaris* (collection of Smoleń, 2011); C – *Lenticulina (Astacolus) volubilis* (collection of Smoleń, 2012); D – *Planularia ex. gr. eugenii* (collection of Smoleń, 2012); E – *Lenticulina daphne* (collection of Bielecka and Styk, 1980); F – *Lenticulina (Astacolus) kujaviana* (collection of Bielecka and Styk, 1980); G – *Ichtyolaria nymphe* (collection of Smoleń, 2011); H – *Lenticulina (Planularia) polymorpha* (collection of Bielecka and Styk, 1981); I, J – *Lenticulina (Astacolus) polymorpha arachne* (collection of Smoleń from the Polik IG-1 borehole, 2016); K1 – *Reinholdella crebra*, ventral side (collection of Smoleń from the Gorzów Wielkopolski IG-1 borehole, 2014); K2 – *Reinholdella crebra*, dorsal side (collection of Smoleń from the Gorzów Wielkopolski IG-1 borehole, 2014); L, M – *Spirillina radiata* (collection of Smoleń, 2012); N – *Paalzowella pazdroe* (collection of Smoleń, 2011); O – *Lenticulina (Astacolus) argonauta* (collection of Smoleń, 2011); P, Q – *Palaeomiliolina czestochowiensis* (collection of Smoleń, 2012); R – *Palaeomiliolina rawiensis* (collection of Smoleń from the Jamno IG-1, IG-2 and IG-3 boreholes, 2008); S – *Vermeulinoides favus* (collection of Kopik, 1956); T – *Triplasia tricarinata* (collection of Bielecka and Styk, 1980); U, W – *Geinitzinita nodosaria* (collection of Smoleń, 2012); X – *Lenticulina helios* (collection of Smoleń, 2012); Y – *Epistomina coronata* (collection of Smoleń from the Brześć Kujawski IG-1, IG-2 and IG-3 boreholes, 2008); scale bars – 100 µm

(Terquem) (Fig. 5U, W), *Palaeomiliolina rawiensis* (Pazdro) (Fig. 5R), and *Lenticulina helios* (Terquem) (Fig. 5X). As evidenced from the studies by Kopik (1998), the Lower Bathonian deposits from the area between Częstochowa and Zawiercie reveal the first occurrences of species such as *Globuligerina bathoniana* (Pazdro), *Trocholina conica* (Schlumberger) and *Verneuilinoides witkowiensis* Bielecka et Styk, known in the rest of the Polish Lowlands from the Middle Bathonian onwards.

Middle Bathonian deposits of the Polish Lowlands also contain multi-species foraminiferal assemblages. Many species continue from the previous zones; however, there is a change in the quantitative proportions between the individual taxa. Continual stratigraphic ranges are characteristic of the following species (Fig. 4): *Palaeomiliolina czestochowiensis* (Pazdro) (Fig. 5P, Q), *P. rawiensis* (Pazdro), *Ophthalmidium carinatum agglutinans* Pazdro, *Epistomina nuda* Terquem, *E. regularis* Terquem, *Reinholdella crebra* Pazdro (Fig. 5K1, K2), *Lenticulina helios* (Terquem), and *Globuligerina bathoniana* (Pazdro) (Fig. 6B). Other numerous occurring taxa are *Lenticulina* (A.) *volubilis* Dain, *L. mamillaris* (Terquem), *Trocholina conica* (Schlumberger) (Fig. 6A1, A2), *Paalzwella pazdroe* Bielecka et Styk (Fig. 5N), *Lenticulina* (*Astacolus*) *argonauta* Kopik (Fig. 5O), *Citharina clathrata* (Terquem) (Fig. 6E) and *Spirillina radiata* Terquem (Fig. 5L, M). The new species that appear in the Middle Bathonian include *Nodosaria plicatilis* Wiśniowski (Fig. 6F), *Garantella sera* Pazdro, *G. arantella* aff. *stellata* Kaptarenko and *Epistomina bireticulata* (Pazdro). Many species, which also occur in the previous zones, terminate their stratigraphic ranges (Fig. 4). Besides these characteristic species, the Middle Bathonian deposits contain species with long age ranges. The most common of such taxa are: *Reophax fusiformis* (Williamson) (Fig. 6M), *Citharina macilenta* (Terquem) (Fig. 6N), *C. oolithica* (Schwager) (Fig. 6O), *Dentalina gumbeli* Hantken (Fig. 6P), *Lagena globosa* (Montagu) (Fig. 6L), *Haplophragmoides canui* Cushman (Fig. 6K) and *Ammodiscus orbis* Laliker (Fig. 6J).

The Upper Bathonian foraminiferal assemblages show lower taxonomical diversity, though the specimens are numerous. Basically, there are no species typical exclusively for this substage except for one new species of *Ammovertella plicata* (Terquem) (Figs. 4 and 6H1, H2) which is known only from the Upper Bathonian in Poland. The Upper Bathonian deposits again contain numerous specimens of the species *Palaeomiliolina czestochowiensis* (Pazdro), *Ophthalmidium carinatum agglutinans* Pazdro, *Epistomina nuda* Terquem, *E. regularis* Terquem, *Trocholina conica* (Schlumberger), *Paalzwella pazdroe* Bielecka and Styk, *Lenticulina mamillaris* (Terquem) and *L. helios* (Terquem), *Paulina paula* (Pazdro) (Fig. 6D), *Verneuilinoides witkowiensis* Bielecka and Styk (Fig. 6C) and *Ammovertella plicata* (Terquem) (Figs. 4 and 6H1, H2). Most foraminiferal species, which were also present in the older strata, became extinct at the end of the Bathonian. In south-central Poland (Częstochowa–Zawiercie region), most foraminiferal species have their last occurrences at the end of clay-muddy sedimentation of the Częstochowa ore-bearing clays (Kopik, 1998). In north-western Poland, where the clay-muddy sedimentation persisted for the longest time, foraminifera are fairly numerous in the uppermost Bathonian, in the Discus Zone. In this region, a few new Callovian species have their first occurrences at the end of the Discus Zone (Bielecka and Styk, 1981b). These are *Epistomina mosquensis* Uhlig, *E. parastelligera* (Hofker) and *Geinitzinita franconica* (Gümbel).

CALLOVIAN

The Callovian/Oxfordian boundary, between the Lamberti and Mariae zones (Fig. 2), has been documented based on ammonites in the Kcynia IG-4 borehole (central Poland; Matyja and Wierzbowski, 1998) and in the Ogrodzieniec Quarry (south-central Poland; Barski et al., 2004; Dembicz et al., 2006). It is also indicated by micropalaeontological investigations carried out in NE Poland (Smoleń, 2000). As regards foraminifera, the biostratigraphic boundary between the Lamberti and Marie zones is reflected by a global change in the foraminiferal assemblages (Grigelis, 1982, 1985; Mesezhnikov et al., 1989).

In the Polish Lowlands, the beginning of the Callovian corresponds to a short marine regression. In central and north-western Poland, sandstones, dolomitic mudstones and sandy dolomites were deposited in a shallow sea (Dayczak-Calikowska, 1977, 1997). In south-central Poland, accumulation of limestones and marls with ooids and calcareous-sandy deposits dominated (Feldman-Olszewska, 1997). In the Herveyi Zone, foraminifera are extremely rare and biostratigraphically insignificant. These are the species that are known from Bathonian deposits (see Figs. 4 and 7). In the Herveyi Zone, the first appearance in Poland of the species *Textularia jurassica* (Gümbel) (Fig. 6S) was noticed (Bielecka and Styk, 1981b). Development of foraminiferal assemblages started in the Calloviense Zone, at the time of the onset of a marine transgression. New foraminifera species appeared, such as: *Dentalina brueckmanni* Mjatluk (Fig. 6U), *Lenticulina pseudocrassa* Mjatluk (Fig. 6Aa), *L. catascopium* (Mitjanina) (Fig. 6W, X), *L. okrojanzii* Mjatluk (Fig. 8A), *L. lithuanica* (Brückmann) (Fig. 8L, M), *L. tumida* (Mjatluk) (Fig. 8B, C), *Pseudolamarckina rjasanensis* (Uhlig) (Fig. 8G1, G2), *Vaginulinopsis rokitae* Bielecka et Styk (Fig. 6Q), *Astacolus protractus* (Bornemann) (Fig. 6T) and *A. limnatus* (Schwager) (Fig. 6Y, Z), which are accompanied by those known from the older deposits (Fig. 7). Large foraminiferal assemblages, mainly of the Middle and Upper Callovian, have been described from clastic deposits represented by muddy-clayey and muddy-marly facies in NW (Bielecka, 1965; Bielecka and Styk, 1981b) and NE Poland (Smoleń, 2000, 2011b, c, 2014b).

In the Middle Callovian, the next species have their first occurrences (see Fig. 7): *Lenticulina ruesti* (Wiśniowski) (Fig. 8H), *L. polonica* (Wiśniowski) (Fig. 8N), *L. ovato acuminata* (Wiśniowski) (Fig. 8T), *L. quenstedtii* (Gümbel) (Fig. 8Aa), *Planularia tricostata* (Mitjanina) (Fig. 8F), *Planularia tricarinnella* (Reuss) (Fig. 8E), *Geinitzinita crassata* Gerke (Fig. 8O, P), *Ichtyolaria supracallovensis* (Wiśniowski) (Fig. 8I, J), *Epistomina elschankaensis* Mjatluk, *Planularia colligata* (Brückmann) (Fig. 8D), *Citharinella moelleri* (Uhlig) (Fig. 8Q), *C. nikitini* (Uhlig) (Fig. 8R), *Astacolus erucaeformis* (Wiśniowski) (Fig. 8U, W), and *Dorothyia osowiensis* Bielecka et Styk (Fig. 8K). In the whole Middle Callovian, there are also numerous specimens of *Epistomina mosquensis* Uhlig (Fig. 6G), *Geinitzinita franconica* (Gümbel) (Fig. 6R), *E. parastelligera* (Hofker) (Fig. 6I1, I2), *Nodosaria mutabilis* (Fig. 8S), *Astacolus folium* (Wiśniowski) (Fig. 9G) and *Pseudolamarckina rjasanensis* (Uhlig) (Fig. 7).

The Upper Callovian foraminiferal assemblages are very large with respect to the number of both species and individuals. They contain almost all species known from the previous zones. A few new species diagnostic for the Upper Callovian appear in the Athleta Zone. These are *Marginulinopsis*

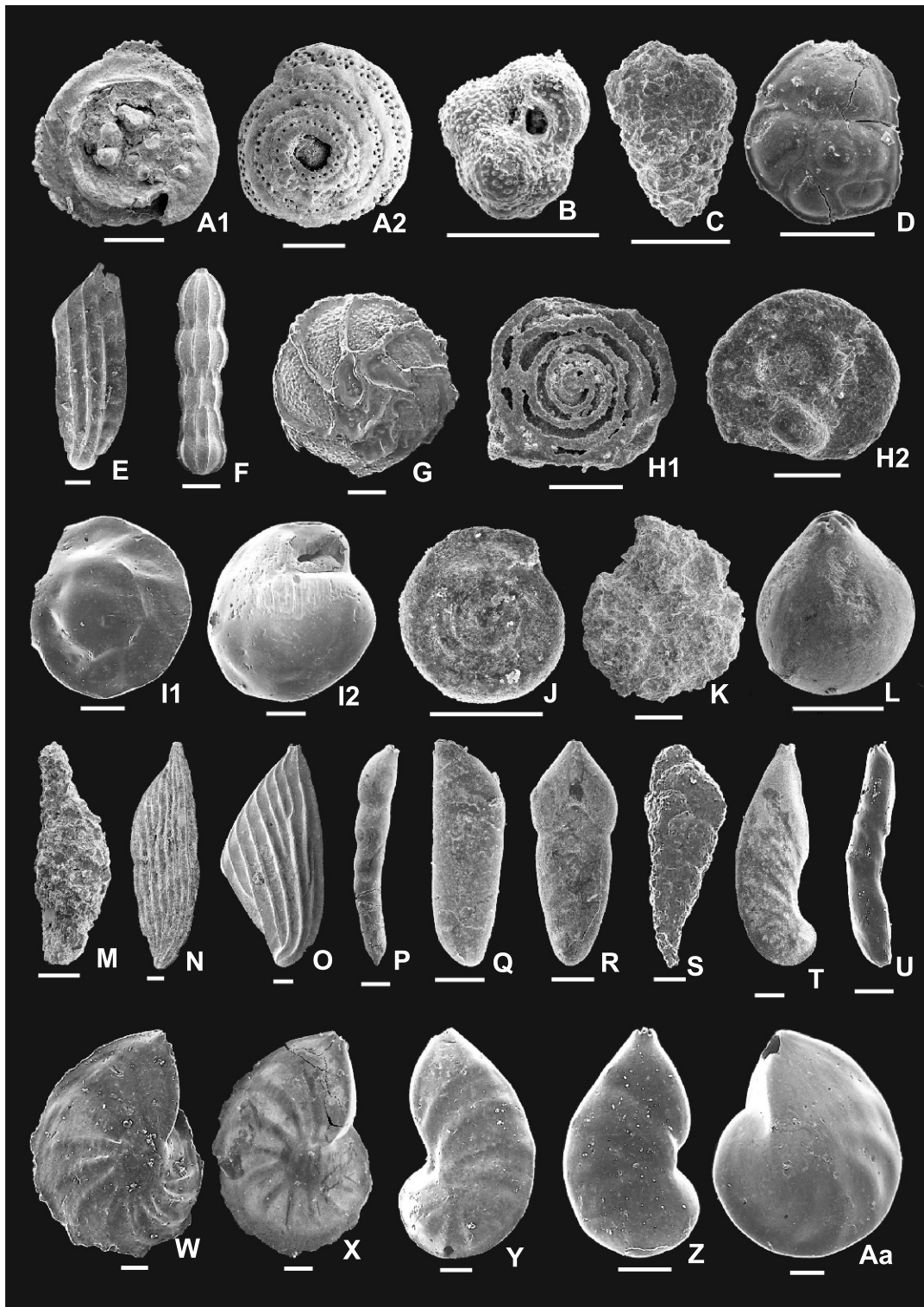


Fig. 6. Foraminifers from the Bathonian deposits (A1–P) and Callovian deposits (Q–Aa) of the Polish Lowlands

A1 – *Trocholina conica*, ventral side (collection of Smoleń from the Jamno IG-1, IG-2 and IG-3 boreholes, 2008); **A2** – *Trocholina conica*, dorsal side (collection of Smoleń from the Jamno IG-1, IG-2 and IG-3 boreholes, 2008); **B** – *Globuligerina bathoniana* (collection of Smoleń, 2012); **C** – *Verneulinoides witkowiensis* (collection of Bielecka and Styk, 1981); **D** – *Paulina paula* (collection of Bielecka and Styk, 1981); **E** – *Citharina clathrata* (collection of Bielecka 1960); **F** – *Nodosaria plicatilis* (collection of Smoleń, 2012); **G** – *Epistomina mosquensis* (collection of Smoleń, 2000); **H1** – *Ammovertella plicata*, ventral side (collection of Bielecka and Styk, 1980); **H2** – *Ammovertella plicata*, dorsal side (collection of Bielecka and Styk, 1980); **I1** – *Epistomina parastelligera*, dorsal side (collection of Smoleń, 2015); **I2** – *Epistomina parastelligera*, ventral side (collection of Smoleń, 2015); **J** – *Ammodiscus orbis* (collection of Smoleń, 2011); **K** – *Haplophragmoides canui* (collection of Bielecka and Styk, 1980); **L** – *Lagena globosa* (collection of Smoleń, 2011); **M** – *Reophax fusiformis* (collection of Smoleń from the Gorzów Wielkopolski IG-1 borehole, 2014); **N** – *Citharina macilenta* (collection of Smoleń from the Gorzów Wielkopolski IG-1 borehole, 2014); **O** – *Citharina oolithica* (collection of Smoleń, 2011); **P** – *Dentalina gumbeli* (collection of Smoleń from the Gorzów Wielkopolski IG-1 borehole, 2014); **Q** – *Vaginulinopsis rokitae* (collection of Bielecka and Styk, 1981); **R** – *Geinitzinita franconica franconica* (collection of Bielecka and Styk, 1981); **S** – *Textularia jurassica* (collection of Smoleń, 1998); **T** – *Astacolus protractus* (collection of Smoleń from the Jamno IG1, IG2 and IG3 boreholes, 2008); **U** – *Dentalina brueckmanni* (collection of Smoleń, 2000); **W, X** – *Lenticulina catascopium* (collection of Smoleń, 2000); **Y, Z** – *Astacolus limnatus* (collection of Smoleń, 2000); **Aa** – *Lenticulina pseudocrassa* (collection of Smoleń, 2000); scale bars – 100 µm

CALLOVIAN						OXFORDIAN	STAGES		
LOWER			MIDDLE		UPPER		SUBSTAGES		
Herveyi	Koenigi	Calloviense	Jason	Coronatum	Athleta	Lamberi	Mariae	ZONES	Standard Submediterranean ammonite zonation
								Foraminifera	
									<i>Lenticulina mamillaris</i> (Terquem)
									<i>Epistomina nuda</i> Terquem
									<i>Ophthalmidium carinatum agglutinans</i> Pazdro
									<i>Epistomina regularis</i> Terquem
									<i>Citharina heteropleura</i> (Terquem)
									<i>Palaeomiliolina czestochowiensis</i> (Pazdro)
									<i>Paalzowella pazdroe</i> Bielecka et Styk
									<i>Spirillina radiata</i> Terquem
									<i>Nodosaria plicatilis</i> Wiśniowski
									<i>Geinitzinita franconica franconica</i> (Gümbel)
									<i>Textularia jurassica</i> (Gümbel)
									<i>Ammobaculites fontinensis</i> (Terquem)
									<i>Trocholina conica</i> (Schlumberger)
									<i>Epistomina mosquensis</i> Uhlig
									<i>Epistomina parastelligera</i> (Hofker)
									<i>Dentalina brueckmanni</i> Mjatluk
									<i>Astacolus protractus</i> (Bornemann)
									<i>Vaginulinopsis rokitaie</i> Bielecka et Styk
									<i>Lenticulina pseudocrassa</i> Mjatluk
									<i>Lenticulina catascopium</i> (Mitjanina)
									<i>Astacolus limnatus</i> (Schwager)
									<i>Lenticulina okrojanzii</i> Mjatluk
									<i>Pseudolamarckina rjasanensis</i> (Uhlig)
									<i>Lenticulina tumida</i> Mjatluk
									<i>Planularia colligata</i> (Brückmann)
									<i>Planularia tricostata</i> (Mitjanina)
									<i>Lenticulina lithuanica</i> (Brückmann)
									<i>Lenticulina ruesti</i> (Wiśniowski)
									<i>Epistomina elschankaensis</i> Mjatluk
									<i>Ichtyolaria supracallovienensis</i> (Wiśniowski)
									<i>Dorothia oswienensis</i> Bielecka et Styk
									<i>Lenticulina polonica</i> (Wiśniowski)
									<i>Geinitzinita crassata</i> (Gerke)
									<i>Citharinella moelleri</i> (Uhlig)
									<i>Citharinella nikitini</i> (Uhlig)
									<i>Lenticulina ovato acuminata</i> (Wiśniowski)
									<i>Astacolus erucaeformis</i> (Wiśniowski)
									<i>Palmula subparalella</i> (Wiśniowski)
									<i>Lenticulina papillaeostata</i> Bielecka et Styk
									<i>Lenticulina laminaesuturata</i> Bielecka et Styk
									<i>Marginulinopsis batrakiensis</i> (Mjatluk)
									<i>Pachyphloides glandulinooides</i> (Wiśniowski)
									<i>Saracenaria engelsensis</i> Kosyrev
									<i>Epistomina planiconvexa</i> Bielecka et Styk
									<i>Palaeomiliolina michalskii</i> (Wiśniowski)
									<i>Palaeomiliolina difficilis</i> (Wiśniowski)
									<i>Ophthalmidium carinatum marginatum</i> (Wiśniowski)

Fig. 7. Stratigraphic range charts of foraminifera species from the Callovian deposits of the Polish Lowlands, ammonite zonation as used by Kopik (1998, modified), Barski et al. (2004) and Dembicz et al. (2006)

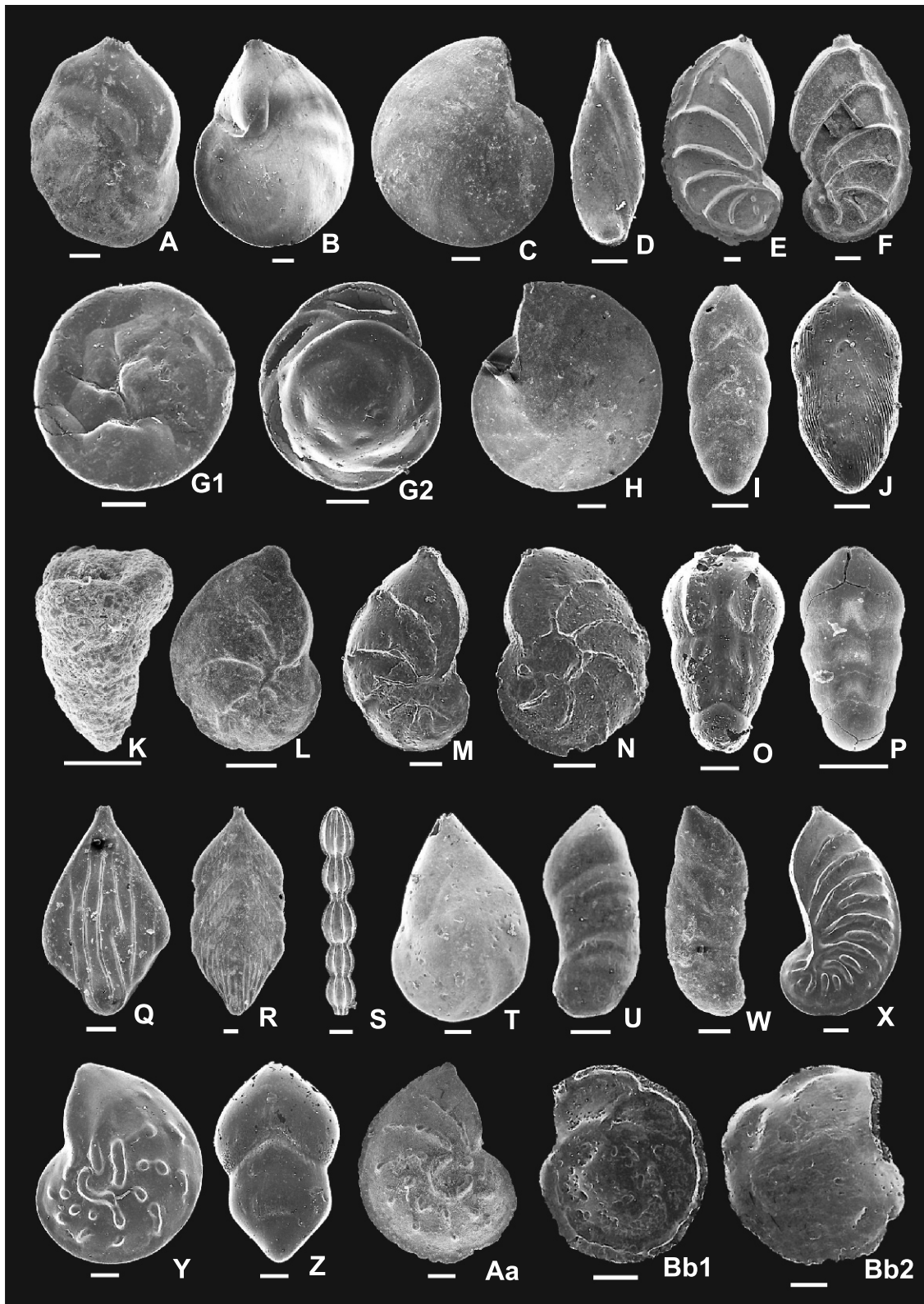


Fig. 8. Foraminifers from the Callovian deposits of the Polish Lowlands

A – *Lenticulina okrojanzii* (collection of Smoleń, 2000); **B, C** – *Lenticulina tumida* (collection of Smoleń, 2000); **D** – *Planularia colligata* (collection of Smoleń, 2000); **E** – *Planularia tricarinella* (collection of Smoleń, 2000); **F** – *Planularia tricostata* (collection of Smoleń, 2000); **G1** – *Pseudolamarckina rjasanensis*, ventral side (collection of Smoleń, 2000); **G2** – *Pseudolamarckina rjasanensis*, dorsal side (collection of Smoleń, 2000); **H** – *Lenticulina ruesti* (collection of Smoleń, 2000); **I, J** – *Ichthyolaria supracallovienensis* (collection of Smoleń, 2000); **K** – *Dorothia osowiensis* (collection of Bielecka and Styk, 1981); **L, M** – *Lenticulina lithuanica* (collection of Smoleń, 2000); **N** – *Lenticulina polonica* (collection of Smoleń, 2000); **O, P** – *Geinitzinita crassata* (collection of Smoleń, 2000); **Q** – *Citharinella moelleri* (collection of Bielecka and Styk, 1981); **R** – *Citharinella nikitini* (collection of Bielecka and Styk, 1981); **S** – *Nodosaria mutabilis* (collection of Smoleń, 2000); **T** – *Lenticulina ovato acuminata* (collection of Smoleń, 2000); **U, W** – *Astacolus erucaeformis* (collection of Smoleń, 2000); **X** – *Saracenaria engelsensis* (collection of Smoleń, 2000); **Y** – *Lenticulina papillaeocostata* (collection of Smoleń, 2000); **Z** – *Pachyphloides glanduloides* (collection of Smoleń, 2000); **Aa** – *Lenticulina quenstedtii* (collection of Smoleń, 2000); **Bb1** – *Epistomina planiconvexa*, dorsal side (collection of Smoleń, 2000); **Bb2** – *Epistomina planiconvexa*, ventral side (collection of Smoleń, 2000); scale bars – 100 µm

batrakiensis (Mjatiuk), *Saracenaria engelsensis* Kosyrev (Fig. 8X), *Planularia paralella* (Schwager) (Fig. 9F), *Palmula subparalella* (Wiśniowski), *Epistomina planiconvexa* Bielecka et Styk (Fig. 8Bb1, Bb2), *Ophthalmidium carinatum marginatum* (Wiśniowski) (Fig. 9D, E), *Palaeomiliolina michalskii* (Wiśniowski) (Fig. 9A, B), *P. difficilis* (Wiśniowski) (Fig. 9C), *Lenticulina papillaecostata* Bielecka et Styk (Fig. 8Y), *L. laminaesuturata* Bielecka et Styk and *Pachyphloides glanduloides* (Wiśniowski) (Figs. 7 and 8Z).

The Callovian foraminiferal assemblages are characterized by a considerable proportion of taxa described from northeastern European regions. Taxonomic analysis of Upper Callovian foraminiferal assemblages from NE Poland has allowed distinguishing the foraminiferal *Lenticulina tumida* Zone (Grigelis, 1982) within the limits of the ammonite zones of Duncani (= *Athleta*) and Lamberti (Smoleń, 2000). Such zone was previously established by Grigelis (1982, 1985) and Mesezhnikov et al. (1989) within the range of the *Athleta* and *Lamberti* zones in the European part of the East European Platform.

In the remaining part of the Polish Lowlands, where the Upper Callovian is represented by the nodular bed or by organodetrital limestones (eastern Poland), which are often diagenetically changed, foraminifera microfossils are preserved rarely (Dayczak-Calikowska and Marcinkiewicz, 1997). In south-central Poland (Kraków–Wieluń Upland), relatively large Upper Callovian foraminiferal assemblages have been found locally only in marly and clayey deposits in the south of the Kraków–Wieluń Upland (Wiśniowski, 1890; Bielecka, 1960a; Olszewska and Wieczorek, 1988; Siewniak, 1962). In the north of the upland, between Częstochowa and Zawiercie, Kopik (1998) has determined only a few foraminiferal species in the lower Upper Callovian (*Athleta* Zone). At the end of the Middle Jurassic, most foraminiferal species have their last occurrences. The Oxfordian deposits contain only few Middle Jurassic species.

UPPER JURASSIC

OXFORDIAN

A clear differentiation in palaeogeographical provinces is observed in Europe during the Oxfordian. In the Polish Lowlands, an epicontinental marine basin existed at that time, which was connected to the Tethys Ocean and the northern seas (e.g., Marek and Pajchłowa, 1997; Fig. 10). Different sedimentary conditions in the individual parts of the Polish Basin and varying influences from the palaeogeographical provinces greatly affected the development of ammonite faunas. Faunal assemblages show significant differences between southern, eastern and central Poland (with typically different types of sponge megafacies carbonates) and the regions of northern Poland (with mudstone-claystone and mudstone-sandstone deposits of the Łyna Formation; Fig. 11). The presence of ammonites, characteristic of different palaeogeographical provinces, resulted in the usage of different stratigraphic schemes in Poland. They were based on either Boreal or Submediterranean divisions.

Over the last few decades, much work has been carried out on biostratigraphical correlations of the Oxfordian and Kimmeridgian between the individual provinces. The research has resulted in both the correlation of ammonite zonation between the Subboreal, Boreal and Submediterranean biogeographical provinces, and the proposal of unification of the Oxfordian/Kimmeridgian boundary for all palaeogeographical provinces. A substantial change refers to the position of this

boundary in the Submediterranean Province. According to the recently proposed scheme, the boundary is placed between the Hypselum and Bimammatum zones. The lower boundary of the new substage corresponds to the lower boundary of the Subboreal ammonite zone of Baylei, and to the lower boundary of the Boreal zone of Bauhini (Wierzbowski and Matyja, 2014; Wierzbowski et al., 2015, 2016). As a result of the redefined Oxfordian division in the Submediterranean Province, the Hypselum Subzone (previously a subzone of the Bimammatum Zone) has been elevated to the rank of 'zone', and the Bimammatum and *Planula* zones have been moved to the Kimmeridgian (see Wierzbowski et al., 2016: p. 30, fig. 7). At the same time, the new proposal of the lower boundary of the unified Upper Oxfordian Substage in the Submediterranean Province has been put up by Głowniak (2006a) who considers this boundary as coeval with the base of the redefined *Bifurcatus* Zone (with the *Wartae* Subzone as the basal subzone of the *Bifurcatus* Zone). Simultaneously, the so-defined lower boundary of the *Bifurcatus* Zone corresponds to the boundary between the Middle and Upper Oxfordian substage (Głowniak 2006a). The aim of this change was to obtain a close correlation of the lower boundaries of the Upper Oxfordian Substage between the Boreal and the Submediterranean provinces. The lower boundary of the Boreal Upper Oxfordian lies close to, but somewhat below the equivalent substage boundary in the Submediterranean Province, falling in the uppermost part of the *Transversarium* Zone (cf. Matyja and Wierzbowski, 1994; Głowniak 2006a; Wierzbowski et al., 2015).

FORAMINIFERAL ASSEMBLAGES: CENTRAL, SOUTHERN AND EASTERN POLAND

In the southern, eastern and central parts of Poland, the Oxfordian basin was an area of carbonate sedimentation (sponge megafacies). The Early Oxfordian was dominated by sedimentation of the Spongy Limestone Formation. In the Middle Oxfordian, the Coraliferous Formation developed in some areas of central and eastern Poland. The Late Oxfordian was a period of the oolitic limestone (Oolitic Formation) development (see Niemczycka, 1997).

The first micropalaeontological reports on the characteristics of foraminiferal assemblages and their stratigraphical significance dealt with data from exposures and boreholes in the Kraków–Wieluń Upland (Bielecka, 1956, 1960a; Olszewska and Wieczorek, 1988, Siewniak, 1962), as well as from boreholes drilled in central (Bielecka, 1960b, 1961; Bielecka and Styk, 1964, 1968) and eastern Poland (Bielecka, 1964). The works and numerous archived micropalaeontological documentations of boreholes drilled in these parts of the Polish Lowlands resulted in the compilation of charts of the range of the most important foraminiferal species, correlated with the regional biostratigraphic schemes and presented by Bielecka (1980) and Styk (1997). In the above-mentioned publications, the age ranges of the Oxfordian foraminiferal species were correlated with the ammonite biostratigraphy established by Malinowska (1976, 1991a, b), which was based on ammonites typical of the Boreal and Sub-Boreal provinces, and with reference to the stratigraphic divisions established for these provinces. The results of the latest research on the distribution of ammonite faunas in the sponge megafacies deposits show unambiguously the dominance of Submediterranean species and the validity of the Submediterranean stratigraphic scheme for these areas (Głowniak, 2002, 2006a, b, 2012; Wierzbowski and Matyja, 2014; Wierzbowski et al., 2015, 2016).

Correlation of the stratigraphic ranges of foraminiferal species in the sponge megafacies deposits with the standard

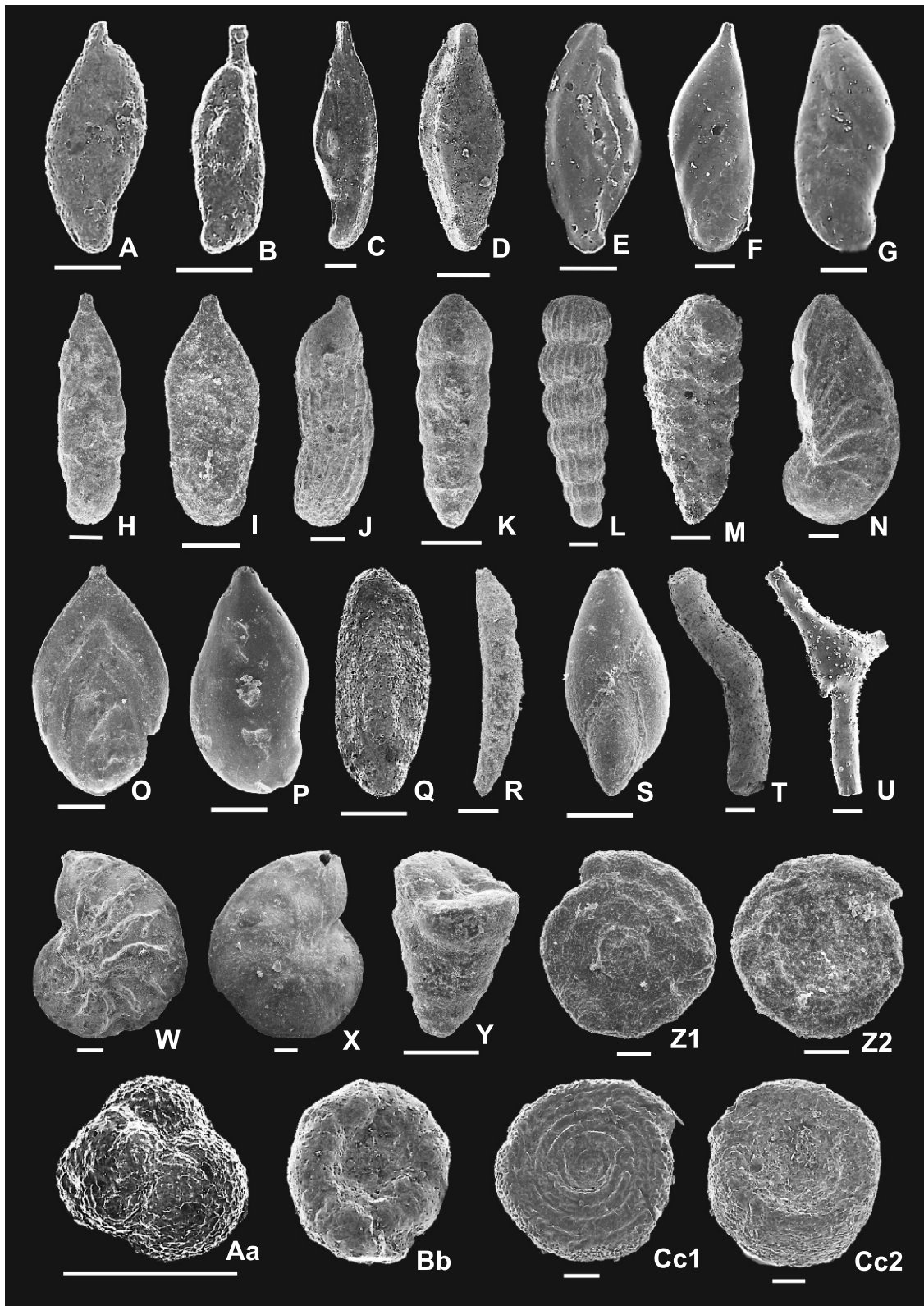


Fig. 9. Foraminifers from the Upper Callovian deposits (A–G) and Oxfordian Sponge Megafacies carbonates (H–Cc2) of the Polish Lowlands

A, B – *Palaeomiliolina michalskii* (collection of Smoleń, 2000); **C** – *Palaeomiliolina difficilis* (collection of Smoleń, 2000); **D, E** – *Ophthalmidium carinatum marginatum* (collection of Smoleń, 2000); **F** – *Planularia paralella* (collection of Smoleń, 2000); **G** – *Astacolus folium* (collection of Smoleń, 2000); **H, I** – *Palmula subparalella* (collection of Bielecka, 1960); **J** – *Marginulinopsis radiata* (collection of Bielecka, 1960); **K** – *Lingulina laevissima* (collection of Bielecka, 1960); **L** – *Nodosaria raphanistriformis* (collection of Bielecka, 1960); **M** – *Textularia jurassica* (collection of Smoleń, 1998); **N** – *Saracenaria cornucopiae* (collection of Smolen, 1998); **O** – *Falsopalmula deslongchampsii* (collection of Smoleń, 1998); **P** – *Astacolus folium* (collection of Bielecka, 1960); **Q** – *Miliammina olgae* (collection of Smoleń, 1998); **R** – *Dentalina jurensis* (collection of Bielecka, 1960); **S** – *Eoguttulina oolithica* (collection of Bielecka, 1960); **T** – *Soccorhisa ramosa* (collection of Smoleń, 1998); **U** – *Ramulina spandeli* (collection of Smoleń, 2015); **W** – *Lenticulina quenstedti* (collection of Smoleń, 2015); **X** – *Lenticulina calva* (collection of Bielecka, 1960); **Y** – *Dorothia jurassica* (collection of Bielecka, 1960); **Z1** – *Spirillina tenuissima* (collection of Smoleń, 1998); **Z2** – *Spirillina tenuissima* (collection of Smoleń, 1998); **Aa** – *Globuligerina oxfordiana* (collection of Smoleń, 1998); **Bb** – *Spirillina polygyrata* (collection of Smoleń, 1998); **Cc1** – *Spirillina andrea* (collection of Smoleń, 1998); **Cc2** – *Spirillina andrea* (collection of Smoleń, 1998); scale bars – 100 µm

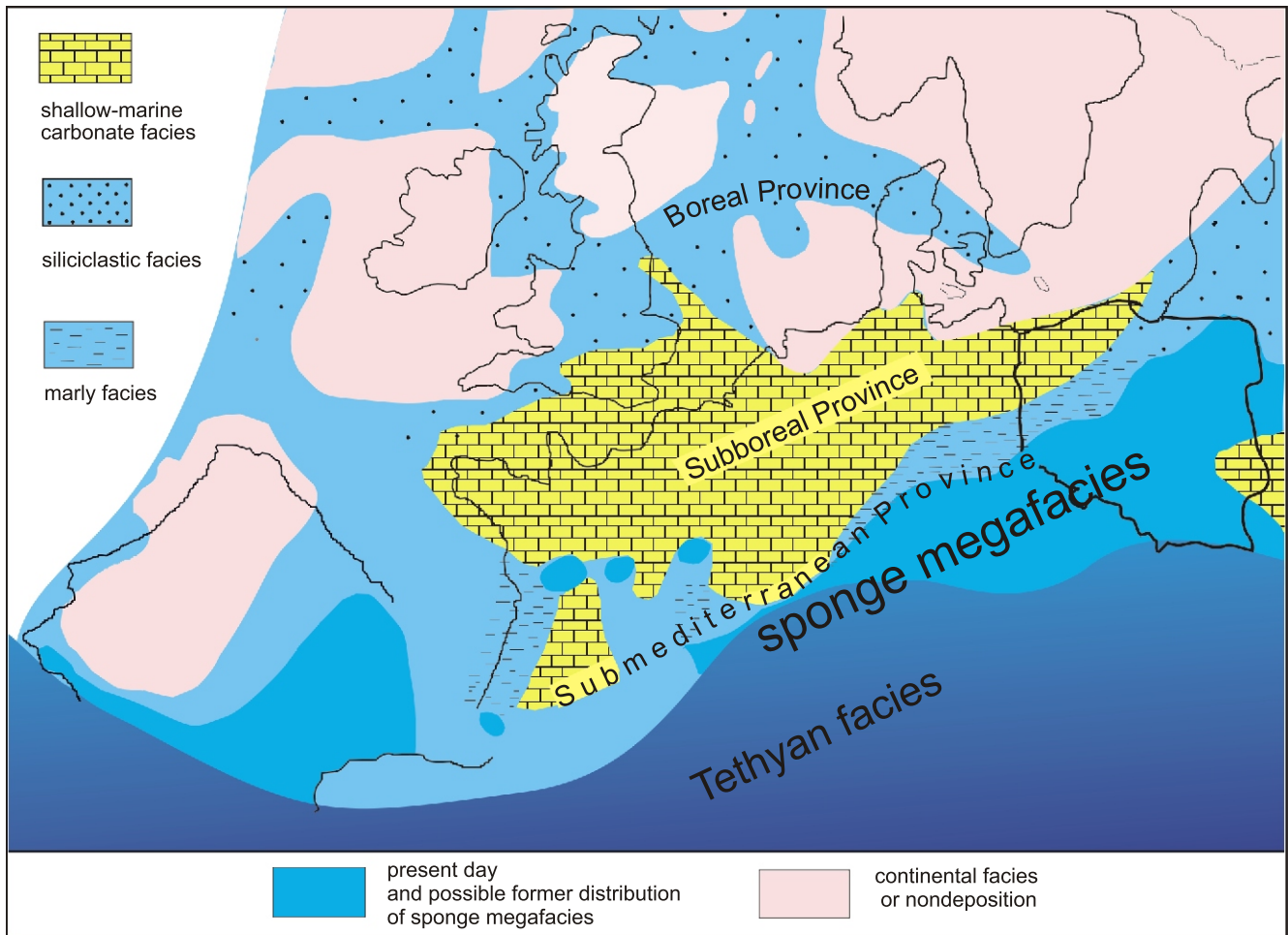


Fig. 10. Palaeogeographic reconstruction showing facies distribution in the Middle to Late Oxfordian transition in Europe (after Matyja and Wierzbowski, 1995)

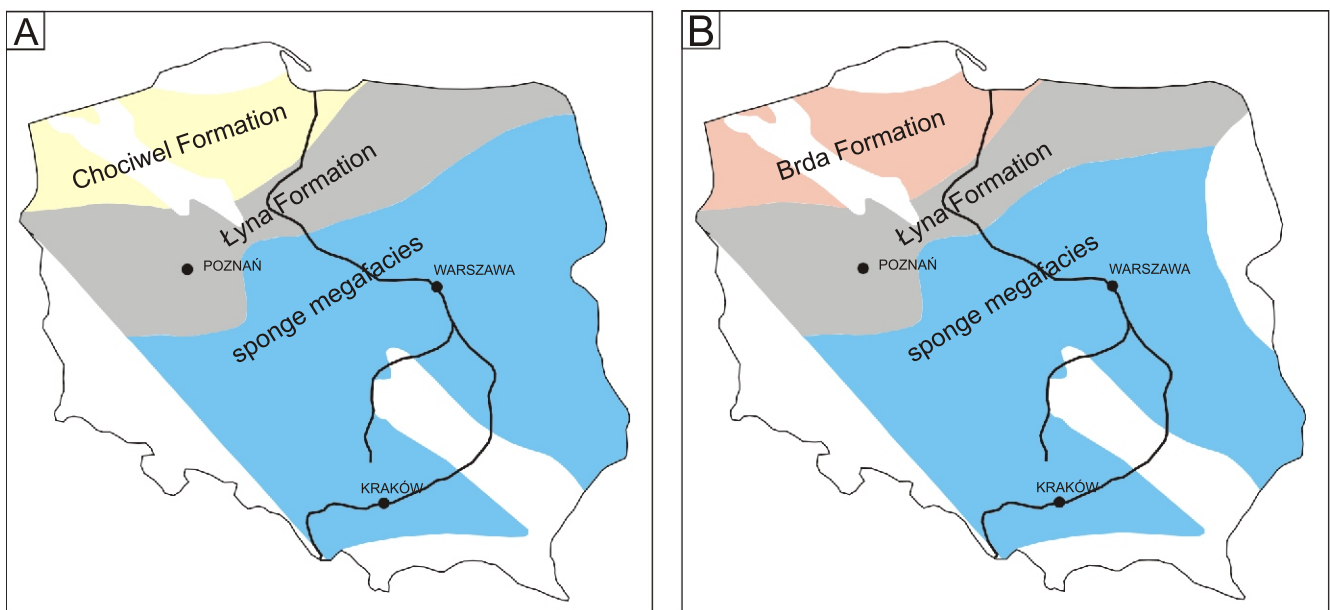


Fig. 11. Sketch of the distribution of lithostratigraphic units of the Lower Oxfordian (A) and Upper Oxfordian–Lower Kimmeridgian (B), after Niemczycka (1997, modified)

ammonite divisions is currently hindered due to the lack of simultaneous research on ammonite and foraminiferal faunas in typical sponge megafacies sections. Such a correlation has so far been possible in the Kcynia IG-4 borehole (Fig. 12), where detailed revision of the ammonite fauna, previously studied by Dembowska (1964) and later by Malinowska (1966, 1981, 1991a), has been made (Matyja and Wierzbowski, 1998). As proved by the latter authors, ammonites diagnostic for the Submediterranean Province account for >60% of all examined specimens in the Kcynia IG-4 borehole. This enables distinguishing of the Submediterranean ammonite zones. It must be stressed that the Kcynia IG-4 borehole (Fig. 1) is located in the northwestern part of central Poland within an area of silty-clayey-marly facies of the Łyna Formation adjoined to the south by carbonates of the sponge megafacies. Taxonomic analysis of foraminifers, which were described by Bielecka and Styk (1964) in the Kcynia IG-4 borehole, shows that all foraminifers from this borehole were also reported from the carbonate deposits of the sponge megafacies in many works (e.g., Bielecka, 1960a; Siewniak, 1962; Bielecka and Styk, 1968; Smoleń, 1998, 2012c, 2015; Olszewska, 2014). This fact allows a correlation of stratigraphic ranges of the foraminiferal species found in the Kcynia IG-4 borehole with the ammonite zones of the Submediterranean Province (Fig. 12).

With respect to the conclusions of the Kcynia IG-4 borehole studies and analysis of previous micropalaeontological reports (mentioned above), a chart of the stratigraphic ranges of the most important foraminiferal species, characteristic of carbonate deposits of the sponge megafacies in the Polish Lowlands, has been compiled (Fig. 13). However, precise determination of the age ranges of the important foraminiferal species requires further correlations based on the latest data on the Oxfordian standard stratigraphic divisions.

Over much of the area of southern, central and eastern Poland, the Lower Oxfordian sedimentary series starts with condensed deposits of the so-called nodular bed yielding an ammonite fauna of the uppermost Callovian (Lamberti Zone) and the lowermost Oxfordian (Mariae Zone). These deposits contain both Callovian and Lower Oxfordian foraminiferal assemblages which unfortunately cannot be used for precise stratigraphic correlations.

In the southern part of the Kraków–Wieluń Upland, near Chrzanów (Bielecka, 1960a) and Olkusz (Siewniak, 1962), where clay-marly deposits locally occur, microfaunal assemblages contain not only Upper Callovian taxa but also typical Oxfordian foraminiferal species, including *Spirillina tenuissima* Gümbel (Fig. 9Z1, Z2), *Textularia jurassica* (Gümbel) (Fig. 9M), *Lingulina laevissima* (Terquem) (Fig. 9K), *Marginulinopsis radiata* (Terquem) (Fig. 9J), *Nodosaria raphanistriformis* (Gümbel) (Fig. 9L), *Dentalina jurensis* (Gümbel) (Fig. 9R), *Saracenaria cornucopiae* (Schwager) (Fig. 9N), *Lenticulina calva* (Wiśniowski) (Fig. 9X), *L. rotulata* (Lamarck) and *Ramulina spandeli* Paalzow. Above the nodular bed in southern, central and eastern Poland, the Oxfordian section is represented by various types of limestones and marls of the so-called sponge megafacies characteristic of the northern shelf of the Tethys Ocean.

A number of new species appear in the upper Lower Oxfordian (upper part of the Cordatum Zone; Fig. 13), which reached their acme in the Middle Oxfordian – a time of “Mediterranean Spread” (Główniak, 2006b). The Middle Oxfordian deposits of the Plicatilis and Transversarium zones reveal the presence of large foraminiferal assemblages in terms of the number of both species and individuals. The species diversity within the assemblages is manifested only by changes in the number of individuals of particular taxa within the assemblage, depending on the lithology. The largest assemblages are found in the facies of marly limestones and marls. A decrease in the

number of foraminifers was noted in biohermal facies and various types of bedded limestones of interbiohermal zones in south-central Poland in the Kraków–Wieluń Upland (Bielecka, 1960a; Smoleń 1998; Olszewska, 2014) and in central Poland in the Wojszyce and Brześć Kujawski boreholes (Smoleń, 2008b, 2012c). The characteristic species, representing the time interval from the latest Early Oxfordian (upper part of the Cordatum Zone) to the latest Middle Oxfordian (Transversarium Zone), comprise the following taxa (Fig. 13): *Spirillina polygyrata* Gümbel (Fig. 9Bb), *S. tenuissima* Gümbel, *S. andrea* Bielecka (Fig. 9Cc1, Cc2), *Ophthalmidium carinatum marginatum* (Wiśniowski), *Paalzowella feifeli seiboldi* Lutze (Fig. 14L), *P. turbinella* (Gümbel) (Fig. 14M1, M2) and *Globuligerina oxfordiana* Grigelis (Fig. 9Aa), which occur locally as large accumulations. The above-listed species are commonly accompanied by *Miliammina olgae* Bielecka (Fig. 9Q), *Planularia polypora* (Gümbel) (Fig. 14A, B), *P. beierana* (Gümbel) (Fig. 14F), *Citharina flabellata* (Gümbel) (Fig. 14C, D), *C. lepida* (Schwager) (Fig. 14E), *Falsopalmula deslongchampsii* (Terquem) (Fig. 9O), *Saracenaria cornucopiae* (Schwager), *Soccorhisa ramosa* (Brady) (Fig. 9T), *Nubeculinella infraoolithica* (Terquem) (Fig. 14O), *Ramulina spandeli* Paalzow (Fig. 9U), *Lenticulina ruesti* (Wiśniowski), *L. calva* (Wiśniowski), *L. quenstedti* (Gümbel) (Fig. 9W) and *L. rotulata* (Lamarck), *Astacolus folium* (Wiśniowski) (Fig. 9P), *Eoguttulina oolithica* (Terquem) (Fig. 9S), *Guttulina jurassica* (Gümbel) (Fig. 14K) and *Dorothia jurassica* (Mitjanina) (Fig. 9Y). The remaining species present in deposits of the above-mentioned time interval occur in small quantities (see Fig. 13). At the end of the Middle Oxfordian, some species have their last occurrences, including *Miliammina olgae* Bielecka, *Marginulinopsis radiata* (Terquem), *Textularia jurassica* (Gümbel), *Lenticulina ruesti* (Wiśniowski) and *Palmula subparallela* (Wiśniowski) (Bielecka, 1960a). The Upper Oxfordian microfauna is very poor in both species and individuals. The foraminiferal assemblages are similar to those found in older deposits as regards their species composition, but less abundant with respect to the quantity of individuals. Most of the taxa have their upper limits of stratigraphic ranges. The typical species for the Upper Oxfordian deposits are: *Paalzowella feifeli elevata* Lutze (Fig. 14N), *Patellinella cristinae* Bielecka (Fig. 14I, J), *Trocholina nodulosa* Seibold et Seibold, *Discorbis speciosus* Dain (Fig. 14H) and *D. subspeciosus* Bogdanovich et Makarjeva (Fig. 14G1, G2). Relatively abundant are *Spirillina polygyrata* Gümbel, *S. tenuissima* Gümbel, *Paalzowella feifeli seiboldi* Lutze and *P. turbinella* (Gümbel), and some lenticulinids. These assemblages are representative of the Spongy Limestone Formation of south-central and central Poland (e.g., Bielecka, 1960a; Smoleń, 2008b, 2012c).

In SE Poland, where the shallow-marine coral facies developed during the Bifurcatus Zone, the foraminiferal assemblages are highly depleted. In the uppermost Oxfordian Hypselum Zone, a further decrease in the number of both species and individuals is observed in the foraminiferal assemblages (Bielecka, 1960a). They contain single specimens of taxa known from the older Oxfordian deposits, which were tolerant to varying marine environmental conditions: *Spirillina tenuissima* Gümbel, *S. polygyrata* Gümbel, *Paalzowella turbinella* (Gümbel), *P. feifeli elevata* Lutze, *P. feifeli seiboldi* Lutze, *Patellinella cristinae* Bielecka, *Discorbis speciosus* Dain, *D. subspeciosus* Bogdanovich et Makarjeva, *Lingulina laevissima* (Terquem), *A. folium* (Wiśniowski), *Dentalina jurensis* (Gümbel), *Eoguttulina oolithica* (Terquem), *Planularia beierana* (Gümbel) and others. The considerable depletion in foraminiferal abundance was related to the facies development. Particularly poor assemblages are found in compact limestones with a high content of calcium carbonate and in reefal-spongy limestones of Coraliferous Formation of central Poland (e.g., in the Wojszyce and Brześć Kujawski bore-

OXFORDIAN			KIMMERIDGIAN	STAGES			
LOWER	MIDDLE	UPPER	LOWER	SUBSTAGES			
Cordatum + Mariae	Transversarium + Plicatilis	Bifurcatus	Hypselum	Bimammatum	Planula	ZONES	Standard Submediterranean ammonite zonation
						Foraminifera <i>Epistomina parastelligera</i> (Hofker) <i>Lenticulina ovato acuminata</i> (Wiśniowski) <i>Lenticulina quenstedti</i> (Gümbel) <i>Lenticulina ruesti</i> (Wiśniowski) <i>Lenticulina calva</i> (Wiśniowski) <i>Lenticulina rotulata</i> (Wiśniowski) <i>Astacolus folium</i> (Wiśniowski) <i>Textularia jurassica</i> (Gümbel) <i>Spirillina tenuissima</i> Gümbel <i>Eoguttulina oolithica</i> (Terquem) <i>Ramulina spandeli</i> Paalzow <i>Astacolus protractus</i> (Bornemann) <i>Falsopalmula deslongchampsii</i> (Terquem) <i>Planularia beierana</i> (Gümbel) <i>Ophthalmidium carinatum marginatum</i> (Wiśniowski) <i>Dentalina jurensis</i> (Gümbel) <i>Nodosaria raphanistriformis</i> (Gümbel) <i>Marginulinopsis radiata</i> (Terquem) <i>Trocholina conica</i> (Schlumberger) <i>Epistomina mosquensis</i> Uhlig <i>Miliammina olgae</i> Bielecka <i>Planularia polypora</i> (Gümbel) <i>Rectoglandulina vulgata</i> (Bornemann) <i>Nubeculinella infraoolithica</i> (Terquem) <i>Soccorhisa ramosa</i> (Brady) <i>Paalzwella turbinella</i> (Gümbel) <i>Astacolus varians</i> (Bornemann)	
Cordatum + Mariae	Transversarium + Plicatilis	Bifurcatus	(Hypselum)	Bimammatum	Planula	ZONES	Ammonite zones (Matyja and Wierzbowski, 1998)
LOWER	MIDDLE	UPPER		SUBSTAGES		STAGES	
OXFORDIAN				STAGES			

Fig. 12. Distribution of foraminifera species in the Kcynia IG-4 borehole and the correlation of the standard Submediterranean Oxfordian ammonite zonations as proposed by Główniak (2002, 2006a), Wierzbowski and Matyja (2014) and Wierzbowski et al. (2015) with the previous Oxfordian subdivision as used by Matyja and Wierzbowski (1998)

Grey blocks indicate the intervals of stratigraphic confidence

holes – Smoleń, 2008b, 2012c). In the eastern regions of the Polish Lowlands, where the oolitic and organodetritic limestones of the Oolitic Formation predominate, foraminiferal microfauna is observed sporadically.

FORAMINIFERAL ASSEMBLAGES:
NORTHERN AND NORTHEASTERN POLAND

In the northern and northeastern part of the Polish Lowlands, Oxfordian deposits are represented by terrigenous formations. In most areas of N and NE Poland, they are composed of silty-clayey-marly facies (Łyna Formation). In the northwest-

ern part, this formation comprises only the Lower Oxfordian, and is followed in the upper Oxfordian by the sandy-chlorite Chociwel Formation that was replaced at the end of the Oxfordian by the oolitic Brda Formation (Fig. 11).

During Oxfordian times, the territory of northern Poland was an area where the influences of various palaeogeographical provinces mixed: Submediterranean, Subboreal and Boreal, allowing periodic migration of ammonite faunas. Due to the nature of the deposits and variable influences of the individual palaeogeographical provinces, the facies generally contain foraminiferal assemblages different from those present in the spongy limestone facies of central, southern and eastern Po-

OXFORDIAN				KIMMERIDGIAN	STAGES	
LOWER	MIDDLE	UPPER	LOWER	SUBSTAGES		
Mariae	Cordatum	Plicatilis Transversarium	Bifurcatus Hypselum	Bimammatum	Standard Submediterranean ammonite zonation	
					Foraminifera	
					<i>Lenticulina tumida</i> Mjatluk <i>Epistomina mosquensis</i> Uhlig <i>Trocholina conica</i> (Schlumberger) <i>Lenticulina ruesti</i> (Wiśniowski) <i>Palmula subparallela</i> (Wiśniowski) <i>Marginulinopsis radiata</i> (Terquem) <i>Lenticulina quenstedti</i> (Gümbel) <i>Ophthalmidium carinatum marginatum</i> (Wiśniowski) <i>Epistomina parasteligera</i> (Hofker) <i>Falsopalmula deslongchampsii</i> (Terquem) <i>Ramulina spandeli</i> Paalzow <i>Lenticulina calva</i> (Wiśniowski) <i>Nodosaria raphanistriformis</i> (Gümbel) <i>Lingulina laevissima</i> (Terquem) <i>Textularia jurassica</i> (Gümbel) <i>Spirillina tenuissima</i> Gümbel <i>Astacolus folium</i> (Wiśniowski) <i>Saracenaria cornucopiae</i> (Schwager) <i>Lenticulina rotulata</i> (Lamarck) <i>Dentalina jurensis</i> (Gümbel) <i>Eoguttulina oolithica</i> (Terquem) <i>Spirillina polygyrata</i> Gümbel <i>Miliammina olgae</i> Bielecka <i>Globuligerina oxfordiana</i> Grigelis <i>Planularia polypora</i> (Gümbel) <i>Citharina flabellata</i> (Gümbel) <i>Citharina lepida</i> (Schwager) <i>Dorothia jurassica</i> (Mitjanina) <i>Spirillina andrea</i> Bielecka <i>Planularia beierana</i> (Gümbel) <i>Soccorhisa ramosa</i> (Brady) <i>Nubeculinella infraolithica</i> (Terquem) <i>Paalzowella feifeli seiboldi</i> Lutze <i>Guttulina jurassica</i> (Gümbel) <i>Paalzowella turbinella</i> (Gümbel) <i>Trocholina nodulosa</i> Seibold et Seibold <i>Paalzowella feifeli elevata</i> (Paalzow) <i>Patelinella cristinae</i> Bielecka <i>Discorbis speciosus</i> Dain <i>Discorbis subspeciosus</i> Bogdanovich et Makarjeva	
Mariae	Cordatum	Densiplicatum Tenuiserratum	Glosense Serratum Regulare Rozenkrantzi	Bauhini	Standard Boreal ammonite zonation	
LOWER	MIDDLE	UPPER	LOWER	SUBSTAGES		
OXFORDIAN			KIMMERIDGIAN	STAGES		

Fig. 13. Stratigraphic range charts of foraminifera species from the Oxfordian deposits of the Polish Lowlands (central, southern and eastern Poland); the Submediterranean standard ammonite zonation as used by Głowniak (2002, 2006a) and correlation with the Boreal ammonite zonation as proposed by Wierzbowski et al. (2014, 2015)

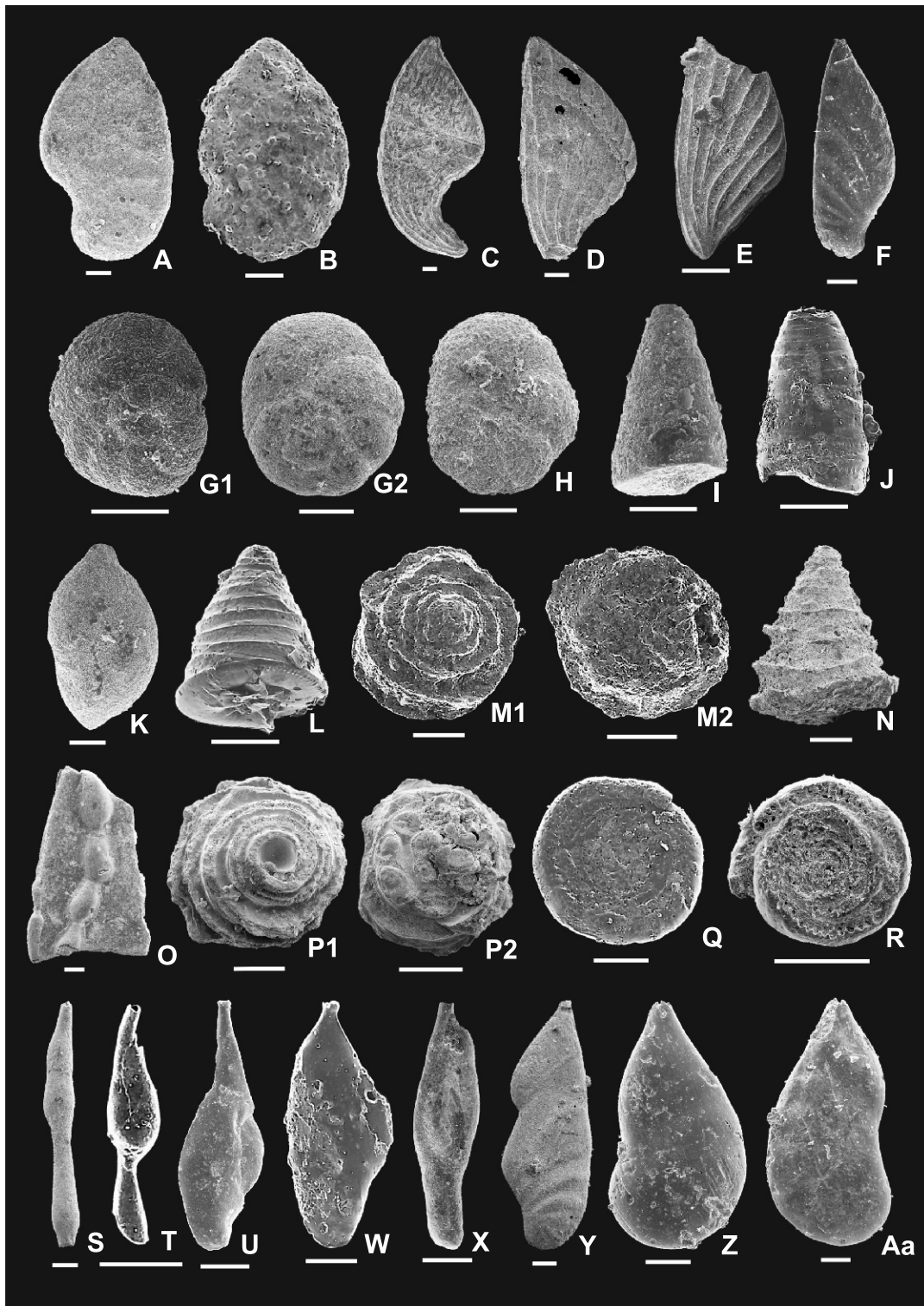


Fig. 14. Foraminifers from the Oxfordian carbonates (sponge megafacies) of the Polish Lowlands (A–O), Oxfordian silty-clayey-marly deposits of the Łyna Formation (*Ophthalmidium sagittum*–*Epistomina volgensis* Zone) of NE Poland (P1–Aa), and Oxfordian–Lower Kimmeridgian silty-clayey-marly deposits of the Łyna Formation (*Lenticulina russiensis*–*Epistomina uhligi* Zone) of NE Poland (X)

A – *Planularia polypora* (collection of Bielecka, 1960); B – *Planularia polypora* (collection of Smoleń 1998); C – *Citharina flabellata* (collection of Bielecka, 1960); D – *Citharina flabellata* (collection of Bielecka, 1960); E – *Citharina lepida* (collection of Bielecka, 1960); F – *Planularia beierana* (collection of Smoleń 1998); G1 – *Discorbis subspeciosus* (collection of Bielecka 1980); G2 – *Discorbis subspeciosus* (collection of Bielecka 1980); H – *Discorbis speciosus* (collection of Bielecka 1980); I – *Patelinella cristinae* (collection of Bielecka 1960); J – *Patelinella cristinae* (collection of Smoleń 1998); K – *Guttulina jurassica* (collection of Bielecka, 1960); L – *Paalzowella feifeli seiboldi* (collection of Smoleń, 1998); M1 – *Paalzowella turbinella* (collection of Smoleń, 1998); M2 – *Paalzowella turbinella* (collection of Smoleń, 1998); N – *Paalzowella feifeli elevata* (collection of Bielecka, 1960); O – *Nubeculinella infraoolithica* (collection of Smoleń, 1998); P1 – *Trocholina transversarii* (collection of Smoleń, 2015); P2 – *Trocholina transversarii* (collection of Smoleń, 2015); Q – *Spirillina polygyrata* (collection of Smoleń, 2015); R – *Spirillina tenuissima* (collection of Smoleń, 2015); S, T – *Nubeculinella infraoolithica* (collection of Smoleń, 2015); U – *Ophthalmidium sagittum* (collection of Smoleń, 2000); W – *Ophthalmidium strumosum* (collection of Smoleń, 2015); Y – *Planularia beierana* (collection of Smoleń, 2015); Z – *Lenticulina compressaeformis* (collection of Smoleń, 2015); Aa – *Lenticulina compressaeformis* (collection of Smoleń, 2015); X – *Ophthalmidium stufense* (collection of Smoleń, 2015); scale bars – 100 µm

land. The first micropalaeontological data concerning the characteristics of foraminiferal assemblages in the Oxfordian deposits of northern Poland and their stratigraphical significance are included in several publications (Bielecka and Dąbrowska, 1958; Bielecka, 1960b, 1973, 1974; Bielecka and Styk, 1966, 1968) and in numerous archival micropalaeontological studies of particular boreholes drilled in this part of the Polish Lowlands. The analysis of previous studies shows that the largest foraminiferal assemblages are present in the silty-clayey-marly deposits of the Łyna Formation, except for the Kcynia IG-4 borehole, where the foraminiferal assemblages are the same as in spongy limestones – see previous chapter.

In the areas extending north of the spongy megafacies, mixed foraminiferal assemblages are found with the vast majority of species being characteristic of the Subboreal Province. Such assemblages have been best documented in NE Poland where there is a complete Oxfordian section represented by silty-clayey-sandy facies. Oxfordian deposits of this region contain numerous foraminifera that were first described by Bielecka and Styk (1966) and Bielecka (1973, 1974). In those studies, the age ranges of the described foraminiferal species were correlated with the ammonite biostratigraphy according to Malinowska (1966), which, in many cases, differs from the standard divisions used currently.

In recent times, detailed studies of the Oxfordian ammonite fauna and foraminiferal microfauna have been carried out in several well-cored boreholes (Paślęk IG-1; Bartoszyce IG-1; Gołdap IG-1; Jastarnia IG-1; Krynica Morska IG-1; Fig. 1) in the area of Peribaltic Syncline (Smoleń, 2000, 2008c; Smoleń and Wierzbowski, 2012). A summary of these studies is published in a paper by Wierzbowski et al. (2015), which also provides a revision of earlier studies by Bielecka and Styk (1966) on the foraminiferal microfauna, as well as a revision of the ammonite stratigraphy proposed by Malinowska (1966, 1987, 1991a). The numerous and palaeogeographically diverse ammonite fauna from the Peribaltic Syncline has allowed a correlation of the ammonite zonation between the Subboreal, Boreal and Submediterranean provinces, and standardization of the Oxfordian/Kimmeridgian boundary across these provinces (Fig. 15). In the context of the new stratigraphic data and detailed chronostratigraphic interpretation of the ammonite fauna, this study provides a chart illustrating the age ranges of stratigraphically important Oxfordian foraminifera species representative of the Łyna Formation in NE Poland (Fig. 15). It also includes micropalaeontological data from other boreholes: Kętrzyn IG-1 (Smoleń, 2014c), Grudziądz IG-1 (Smoleń, 2011d), Darżlubie IG-1 (Smoleń, 2011c) and Malbork IG-1 (Smoleń, 2012d). In terms of taxonomy, the Oxfordian foraminiferal assemblages in the Łyna Formation of NE Poland are most similar to the assemblages described on the East European Platform in Lithuania and in the European part of Russia (e.g., Grigelis, 1985; Ustinova, 2012). These are ophthalmidids–epistominids– and epistominids–lenticulinids-type assemblages classified as characterizing the Sub-Boreal Province (Basov, 1974; Azbel et al., 1991). The vertical succession of foraminiferal species found in Oxfordian deposits of the Peribaltic Syncline in Poland has been the basis for distinguishing foraminiferal zones (Wierzbowski et al., 2015; Fig. 15). Such zones were already established earlier in areas of the East European Platform, in Lithuania and the European part of Russia (e.g., Grigelis, 1982, 1985; Mesezhnikov et al., 1989; Ustinova, 2012).

The Ophthalmidium sagittum–Epistomina volgensis Zone (Grigelis, 1982) can be correlated with the Lower Oxfordian (Mariae, Cordatum zones) and the lowermost Middle Oxfordian (mostly with the lower part of the ammonite Densiplicatum Zone; Fig. 15). This foraminiferal zone is domi-

nated by taxa which are widespread in the eastern part of the Peribaltic Syncline, Lithuania and Russia, indicating strong influences of the Sub-Boreal Province.

The taxa include the index species for this zone: *Epistomina volgensis* Mjatluk (Fig. 16A1, A2) and *Ophthalmidium sagittum* (Bykowa) (Fig. 14U) whose range is limited to the Lower Oxfordian and lower Middle Oxfordian. The other species characteristic of the Ophthalmidium sagittum–Epistomina volgensis Zone are *Epistomina intermedia* Mjatluk (Fig. 16C), *E. nemunensis* Grigelis, *E. stelligeraeformis* Mjatluk, *E. gracilis* Dain (Fig. 16B1, B2), *E. multialveolata* (Grigelis) (Fig. 16D1, D2), *E. uhligi* Mjatluk (Fig. 16E1, E2), *E. parastelligera* Hofker, *Lenticulina brueckmanni* (Mjatluk) (Fig. 16G) and *Planularia beierana* (Gümbel) (Fig. 14Y). The Lower Oxfordian and lowermost Middle Oxfordian contain also some species known from the older deposits, among others *Ichtyolaria supracaloviensis* (Wiśniowski) and *Lenticulina tumida* Mjatluk. The upper part of the Ophthalmidium sagittum–Epistomina volgensis Zone reveals the first occurrences of the following taxa: *Lenticulina compressaeformis* (Paalzw) (Fig. 14Z, Aa), *Ophthalmidium strumosum* (Gümbel) (Fig. 14W), *Globuligerina oxfordiana* Grigelis, *Nubeculinella infraoolithica* (Terquem) (Fig. 14S, T), *Spirillina tenuissima* Gümbel (Fig. 14R), *Spirillina polygyrata* Gümbel (Fig. 14Q) and *Trocholina transversari* (Paalzw) (Fig. 14P1, P2). The above-listed taxa contain widely spread species, also known from the Submediterranean areas.

The Ophthalmidium strumosum–Lenticulina brestica Zone (Grigelis, 1982) can be correlated with a large part of the Middle Oxfordian (from the upper part of the Densiplicatum Zone to the Tenuiserratum Zone, and the Plicatilis and Transversarium zones) and the lower part of the Upper Oxfordian (the Glosense and Serratum zones, a part of the Regulare Zone, as well as a large part of the Bifurcatus Zone; Fig. 15).

Deposits of the Ophthalmidium strumosum–Lenticulina brestica Zone contain especially numerous specimens of species *Ophthalmidium strumosum* (Gümbel). In terms of species diversity, the dominant family is the Epistominidae, of which the species *Epistomina volgensis* Mjatluk and *E. stelligeraeformis* Mjatluk also occur in the lower part of the zone (upper part of the Densiplicatum Zone). *Epistomina nemunensis* Grigelis, *E. intermedia* Mjatluk, *E. gracilis* Dain, *E. multialveolata* (Grigelis), *E. parastelligera* and *E. perfidiosa* Grigelis (Fig. 16F) are numerous throughout the entire zone. They are accompanied by the species *E. uhligi* Mjatluk, *Lenticulina brestica* (Mjatluk) (Fig. 16K), *L. hebetata* (Schwager), *L. brueckmanni* (Mjatluk), *L. simplex* (Kübler et Zwingli) (Fig. 16I), *L. russiensis* (Mjatluk) (Fig. 16L), *L. belorussica* (Mitjanina) (Fig. 16H), *L. tympana* Grigelis (Fig. 16J), *Trocholina transversarii* (Paalzw), *Pseudolamarckina suvalkensis* Grigelis (Fig. 16O), *Paulina furssenkoi* Grigelis (Fig. 16M1, M2), *P. makarensis* Azbel (Fig. 16N1, N2) and others species.

Ophthalmidium strumosum–Lenticulina brestica Zone is dominated by microfauna characteristic of the cool Subboreal Province (Grigelis, 1982, 1985; Mesezhnikov et al., 1989). The deposits, which show predominance of ammonites from the Submediterranean Province, manifest an increased proportion of cosmopolitan foraminifera taxa that are also known from the Submediterranean areas, such as *Globuligerina oxfordiana* (Paalzw) (Fig. 16P), *Nubeculinella infraoolithica* (Terquem), *Orthella bulbifera* (Paalzw) (Fig. 16Q), *O. paalzwii* Bykowa (Fig. 16R), *Paalzwella feifeli seiboldi* Lutze (Fig. 16S), *Ramulina spandeli* Paalzw (Fig. 17B), *Labalina milioliniformis* (Paalzw) (Fig. 17D), *Spirillina tenuissima* Gümbel, *S. polygyrata* Gümbel, *Planularia tricarinnella* (Reuss) (Fig. 17E), *Textularia jurassica* (Gümbel) (Fig. 17A), *Miliamina* cf. *olgae* Bielecka, and others.

OXFORDIAN						KIMME- RIDGIAN	STAGES	
LOWER	MIDDLE	UPPER				LOWER	SUBSTAGES	
Marianae	Cordatum	Densiplicatum	Transversarium	Bifurcatus	Rozenkrantzi	Bauhini (pars)	Boreal	Standard ammonite zonation
		Plicatilis			Globose	Regulare	Pseudocordata	
					Hypselum	Birmatum (pars)	Submediterranean	
O. sagittum -E. volgensis	O. strumosum -L. berestica	L. russiensis -E. uhligi			radiolar. horizon	Foraminiferal zones		
Foraminifera								
<i>Ichtyolaria supracalloviensis</i> (Wiśniowski) <i>Lenticulina tumida</i> Mjatluk <i>Ophthalmidium sagittum</i> (Bykowa) <i>Astaculus erucaeformis</i> (Wiśniowski) <i>Epistomina volgensis</i> Mjatluk <i>Epistomina stelligeraeformis</i> Mjatluk <i>Epistomina gracilis</i> Dain <i>Epistomina intermediata</i> Mjatluk <i>Epistomina multiaalveolata</i> Grigelis <i>Lenticulina brueckmanni</i> (Mjatluk) <i>Planularia beierana</i> (Gümbel) <i>Epistomina ex. gr. parastelligera</i> (Hofker) <i>Epistomina nemunensis</i> Grigelis <i>Epistomina uhligi</i> Mjatluk <i>Lenticulina belorussica</i> (Mitjanina) <i>Lenticulina hebetata</i> (Schwager) <i>Globuligerina oxfordiana</i> (Grigelis) <i>Ophthalmidium strumosum</i> (Gümbel) <i>Nubeculinella infraoolithica</i> (Terquem) <i>Lenticulina compressaeformis</i> (Paalzow) <i>Trocholina transversarii</i> (Paalzow) <i>Spirillina tenuissima</i> Gümbel <i>Spirillina polygyrata</i> Gümbel <i>Epistomina perfidiosa</i> Grigelis <i>Paulina furssenkoi</i> Grigelis <i>Paulina makarensis</i> Azbel <i>Lenticulina simplex</i> (Kübler et Zwingli) <i>Orthella bulbifera</i> (Paalzow) <i>Textularia jurassica</i> (Gümbel) <i>Miliammina olgae</i> Bielecka <i>Pseudolamarckina suvalkensis</i> Grigelis <i>Lenticulina brestica</i> (Mitjanina) <i>Orthella paalzewi</i> Bykowa <i>Ramulina spandeli</i> Paalzow <i>Paalzewella feifeli seiboldi</i> Lutze <i>Labalina milioliniformis</i> (Paalzow) <i>Planularia tricarinnella</i> (Reuss) <i>Lenticulina ex. gr. quenstedti</i> (Gümbel) <i>Lenticulina sublenticularis</i> (Schwager) <i>Lenticulina russiensis</i> (Mjatluk) <i>Ichtyolaria tundrica</i> Azbel <i>Ophthalmidium stufense</i> (Paalzow)								

Fig. 15. Stratigraphic range charts of foraminifera species from the Oxfordian deposits of the Polish Lowlands (N and NE Poland); the correlation of the Boreal and Subboreal ammonite zonations (as proposed by Wierzbowski et al., 2014, 2015) with the Submediterranean zonation (as used by Głowniak, 2002, 2006a)

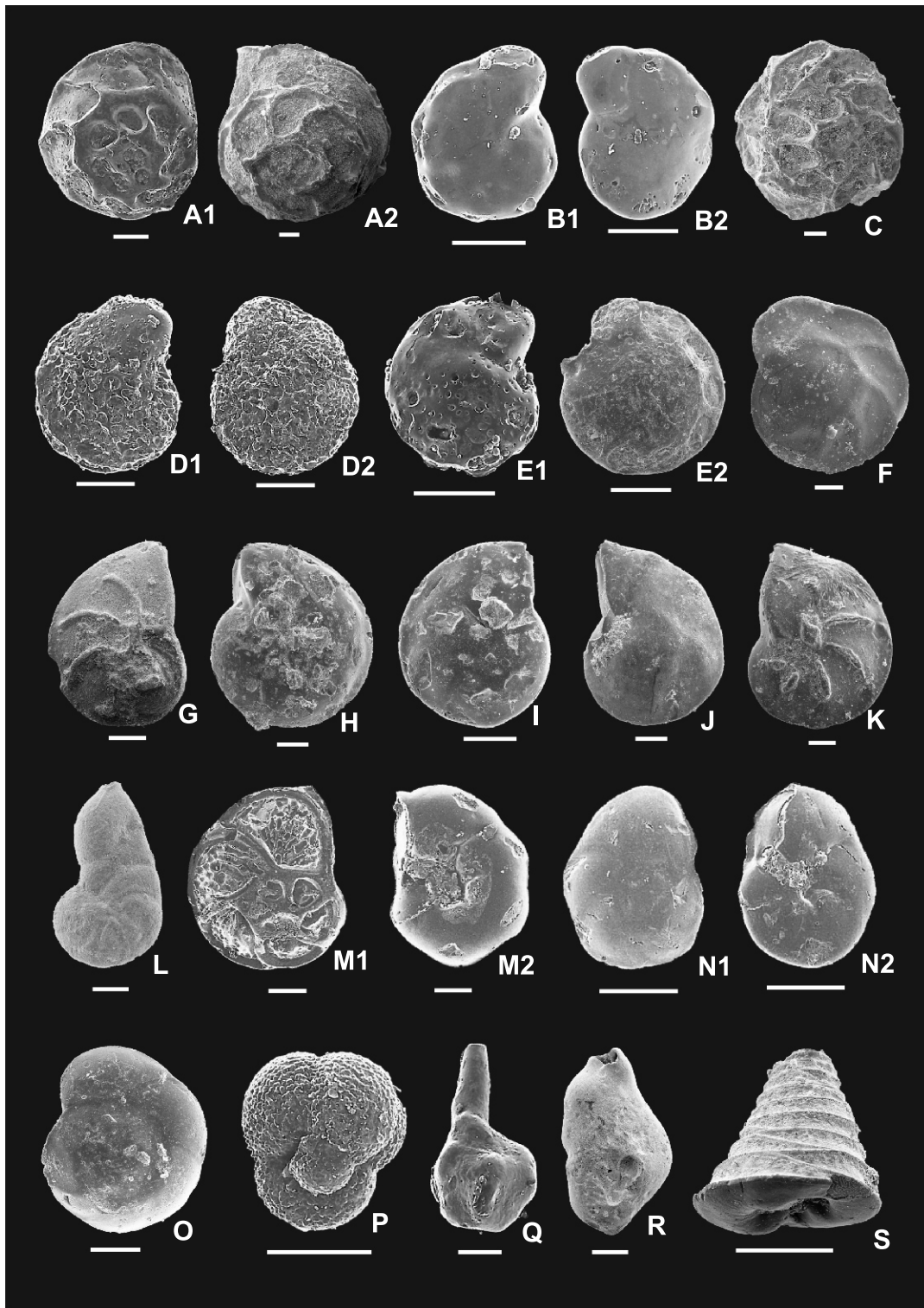


Fig. 16. Foraminifers of the Oxfordian silty-clayey-marly deposits of the Łyna Formation of NE Poland (Ophthalmidium sagittum–Epistomina volgensis Zone; A1–E2, G, and Ophthalmidium strumosum–Lenticulina brestica Zone, F, H–S) of NE Poland

A1 – *Epistomina volgensis* (collection of Smoleń, 2015); **A2** – *Epistomina volgensis* (collection of Smoleń, 2015); **B1** – *Epistomina gracilis* (collection of Smoleń, 2015); **B2** – *Epistomina gracilis* (collection of Smoleń, 2015); **C** – *Epistomina intermediata* (collection of Smoleń, 2015); **D1** – *Epistomina multialveolata* (collection of Smoleń, 2000); **D2** – *Epistomina multialveolata* (collection of Smoleń, 2000); **E1** – *Epistomina uhligi* (collection of Smoleń, 2015); **E2** – *Epistomina uhligi* (collection of Smoleń, 2015); **F** – *Epistomina perfidiosa* (collection of Smoleń, 2015); **G** – *Lenticulina brueckmanni* (collection of Smoleń, 2015); **H** – *Lenticulina belorussica* (collection of Smoleń, 2015); **I** – *Lenticulina simplex* (collection of Smoleń, 2015); **J** – *Lenticulina tympa* (collection of Smoleń, 2015); **K** – *Lenticulina brestica* (collection of Smoleń, 2015); **L** – *Lenticulina russiensis* (collection of Smoleń, 2015); **M1** – *Paulina furssenkoi*, dorsal side (collection of Smoleń, 2000); **M2** – *Paulina furssenkoi*, ventral side (collection of Smoleń, 2000); **N1** – *Paulina makarensis*, dorsal side (collection of Smoleń, 2000); **N2** – *Paulina makarensis*, ventral side (collection of Smoleń, 2000); **O** – *Pseudolamarckina suvalkensis* (collection of Smoleń, 2015); **P** – *Globuligerina oxfordiana* (collection of Smoleń 1998); **Q** – *Orthella bulbifera* (collection of Smoleń, 2015); **R** – *Orthella paalzowi* (collection of Smoleń, 2015); **S** – *Paalzowella feifeli seiboldi* (collection of Smoleń, 2015); scale bars – 100 µm

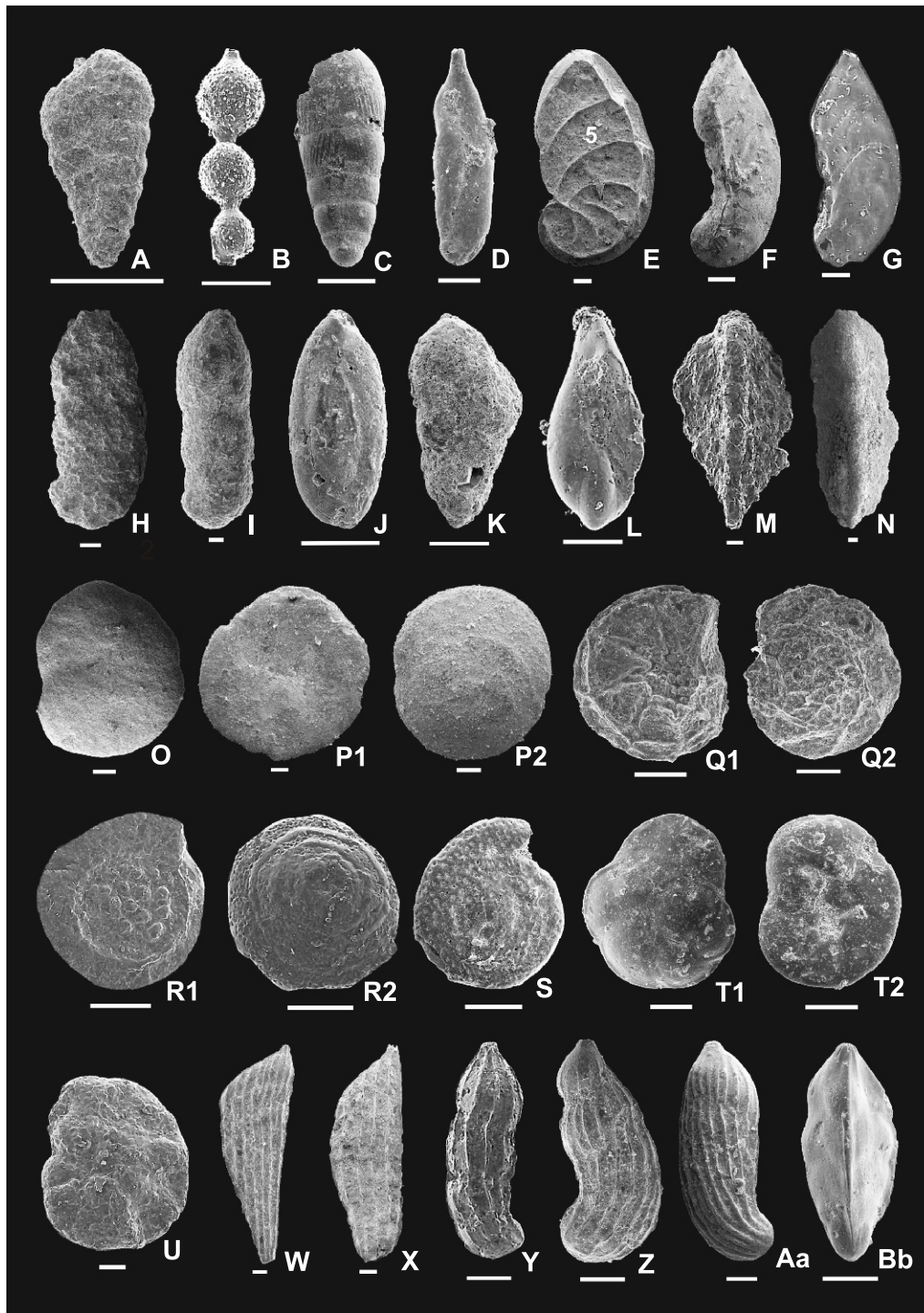


Fig. 17. Foraminifers of the Oxfordian silty-clayey-marly deposits of the Łyna Formation (Ophthalmidium strumosum–Lenticulina brestica Zone) of NE Poland (A, B), Oxfordian–Lower Kimmeridgian silty-clayey-marly deposits of the Łyna Formation (Lenticulina russiensis–Epistomina uhligi Zone) of NE Poland (C–E), Lower Kimmeridgian carbonate deposits of the Polish Lowlands (F–J, L–P2, U–Z) and Lower Kimmeridgian marly deposits of the Łyna Formation (Epistomina praetariensis–Lenticulina kuznetsovae Zone) of NE Poland (K, Q1–T2, Aa, Bb)

A – *Textularia jurassica* (collection of Smoleń, 2015); B – *Ramulina spandeli* (collection of Smoleń, 2015); C – *Ichtyolaria tundrica* (collection of Smoleń, 2015); D – *Labalina milioliniformis* (collection of Smoleń, 2015); E – *Planularia tricarinnella* (collection of Smoleń, 2015); F, G – *Saracenaria cornucopiae* (collection of Bielecka and Styk, 1980); H – *Ammobaculites infrajurensis* (collection of Bielecka and Styk, 1980); I – *Ammobaculites coprolithiformis* (collection of Bielecka and Styk, 1980); J – *Quinqueloculina jurassica* (collection of Bielecka, 1954); K – *Paleogaudryina varsoviensis* (collection of Smoleń, 2015); L – *Eoguttulina inovroclaviensis* (collection of Smoleń, 2015); M, N – *Triplasia althoffi jurassica* (collection of Bielecka and Styk, 1980); O – *Alveosepta jaccardi* (collection of Bielecka and Styk, 1980); P1 – *Pseudolamarckina obliquicamerata*, ventral side (collection of Bielecka and Styk, 1980); P2 – *Pseudolamarckina obliquicamerata*, dorsal side (collection of Bielecka and Styk, 1980); Q1 – *Epistomina stellicostata*, ventral side (collection of Smoleń, 2015); Q2 – *Epistomina stellicostata*, dorsal side (collection of Smoleń, 2015); R1 – *Trocholina solecensis*, ventral side (collection of Smoleń, 2015); R2 – *Trocholina solecensis*, dorsal side (collection of Smoleń, 2015); S – *Spirillina infima* (collection of Smoleń, 2015); T1 – *Conorboides marginata*, dorsal side (collection of Smoleń, 2015); T2 – *Conorboides marginata*, ventral side (collection of Smoleń, 2015); U – *Haplophragmoides canui* (collection of Bielecka and Styk, 1980); W, X – *Citharina zaglobensis* (collection of Smoleń, 2015); Y, Z – *Marginulinopsis buskensis* (collection of Smoleń, 2015); Aa – *Marginulinopsis striatocostata* (collection of Smoleń, 2015); Bb – *Tristix suprajurassica* (collection of Smoleń, 2015); scale bars – 100 µm

In the northernmost area of the Peribaltic Syncline, the Łyna Formation deposits, present in the central syncline, are replaced in the Middle and lowermost Upper Oxfordian by sandstones and sandy siltstones with iron oolites of the Chociwel Formation (documented by ammonites and foraminifers in the Jastarnia IG-1 borehole, [Wierzbowski et al., 2015](#)). These deposits yield large foraminiferal assemblages of the *Ophthalmidium strumosum*–*Lenticulina brestica* Zone. Throughout the whole territory of northeastern Poland, at the end of the *Ophthalmidium strumosum*–*Lenticulina brestica* Zone, the microfaunal assemblages become markedly poorer in terms of the number of taxa, and many of them are absent from the Upper Oxfordian rocks.

The *Lenticulina russiensis*–*Epistomina uhligi* Zone (Grigelis, 1982) corresponds to the uppermost Oxfordian (Rosenkrantz Zone and possibly a part of the Regulare Zone, as well as the Pseudocordata Zone and the Hypselum Zone and possibly the uppermost part of the Bifurcatus Zone), but it covers also the basal part of the Lower Kimmeridgian (lowermost part of the Bauhini Zone, the Baylei Zone and the Bimammatum Zone; [Fig. 15](#)). The foraminiferal assemblages of this zone are impoverished in terms of both the number of species and the quantity of specimens. They are represented by taxa occurring in the lower foraminiferal zones. The characteristic that allows distinguishing the zone is an increased proportion of the species *Epistomina uhligi* Mjatluk, *E. nemunensis* Grigelis and *Lenticulina russiensis* (Mjatluk) in its deposits. Relatively numerous are also the species *Labalina milioliniformis* (Paalow) and *Lenticulina sublenticularis* (Schwager). The remaining taxa distinguished in the *Lenticulina russiensis*–*Epistomina uhligi* Zone are present in a small number of individuals, including the species *Ichtyolaria tundrica* ([Fig. 17C](#)), *Ophthalmidium stufense* (Paalow) ([Fig. 14X](#)), *Planularia tricarinnella* (Reuss), *Lenticulina* ex. gr. *quenstedti* (Gümbel) and others. In the Peribaltic Syncline, the upper limit of the *Lenticulina russiensis*–*Epistomina uhligi* Zone is marked by the last occurrence of most of the Oxfordian foraminifera species in the Lower Kimmeridgian (Bauhini Zone; [Fig. 15](#)).

LOWER KIMMERIDGIAN

According to the proposed stratigraphic scheme (after [Wierzbowski et al., 2016](#)), the Lower Kimmeridgian includes sedimentary series that were previously assigned to the Upper Oxfordian, comprising most of the Bimammatum Zone (excluding the Hypselum Zone) and the Planula Zone. The position of the Oxfordian/Kimmeridgian boundary between the Hypselum and Bimammatum zones has been proved based on ammonite fauna in northeastern Poland and the Peribaltic Syncline ([Wierzbowski et al., 2015](#)), as well as in the Wieluń Upland of central Poland ([Wierzbowski et al., 2016](#)). In the deposits that were previously assigned to the Upper Oxfordian, a species characteristic for the Lower Kimmeridgian appears ([Bielecka and Pożaryski, 1954](#); [Bielecka and Styk, 1964, 1966, 1968](#)). The appearance of Kimmeridgian species in the Planula Zone was reported in a paper on the Wieluń Upland ([Garbowska, 1970](#)) and in a microfaunal report on the Holy Cross region ([Barwicz-Piskorz, 1995](#)). Kimmeridgian foraminifera have also been found in deposits assigned to the Upper Oxfordian (based on lithological and geophysical data) in the recently analyzed deep boreholes of the Polish Lowlands ([Smoleń and Bielecka, 2008](#); [Smoleń, 2011d, 2012c, 2014c, 2015](#)). According to the latest micropalaeontological studies carried out in the Peribaltic Syncline and based on correlation with ammonite zones, foraminiferal assemblages typical of the Lower Kimmeridgian appear in the Subboreal Baylei Zone correlated in that area with

the Submediterranean Bimammatum Zone and the Boreal Bauhini Zone ([Smoleń, 2008c](#); [Smoleń and Wierzbowski, 2012, 2015](#)).

In the Lower Kimmeridgian, like in the Oxfordian, there is a taxonomic diversity within the foraminiferal assemblages depending on the facies type and influences of the individual palaeogeographic provinces. Therefore, this report provides two charts of age ranges of stratigraphically important foraminiferal species representative of carbonate facies ([Fig. 18](#)) and typical of the Łyna Formation in northeastern Poland ([Fig. 19](#)). The greatest taxonomic diversity of the foraminiferal fauna is observed between the area of northeastern Poland (Peribaltic Syncline), where the Lower Kimmeridgian deposits are represented by muddy-clayey-marly facies of the Łyna Formation, and the remaining areas of the Polish Lowlands dominated by various types of carbonates. In the Lower Kimmeridgian, the epicontinental marine basin of the Polish Lowlands remained under the influence of the Submediterranean Province. However, in NE Poland (Peribaltic Syncline) there is a strong influence of the Subboreal Province. This had an impact on the nature of the microfauna, which was marked by the presence, in this part of the Polish Lowlands, of mixed foraminiferal associations.

FORAMINIFERAL ASSEMBLAGES: CENTRAL, EASTERN AND PART OF NORTHERN POLAND

The Lower Kimmeridgian deposits of central, eastern and part of northern Poland are composed of carbonates represented by various types of limestones: oolitic limestone – Brda Formation, marly limestones – Calcareous–Marly–Coquina Formation, and marls – Pałuki Formation (see [Niemczycka, 1997](#)).

Within these deposits, a regional diversity of foraminiferal assemblages is observed. Larger associations with respect to the number of both individuals and taxa are found in marly facies. In contrast, the compact limestones and oolitic limestones show significant depletion in foraminiferal abundance. Deposits of the Bimammatum Zone (after [Wierzbowski et al., 2016](#)) have yielded scarce foraminifers. Foraminiferal assemblages in these deposits do not contain characteristic species but long-ranging taxa known predominantly from Oxfordian deposits. Larger foraminiferal assemblages associated with carbonate facies appear in the Planula Zone ([Fig. 18](#)). Apart from species known from older deposits, they contain a number of new taxa with stratigraphic distributions ranging into the upper series of the Lower Kimmeridgian. In the Planula Zone, the characteristic species include: *Haplophragmoides canui* Cushman ([Fig. 17U](#)), *Alveosepta jaccardi* (Schrodt) ([Fig. 17O](#)), *Pseudolamarckina obliquicamerata* Dulub ([Fig. 17P1, P2](#)), *Quinqueloculina jurassica* Bielecka et Styk ([Fig. 17J](#)), *Trocholina solecensis* Bielecka et Pożaryski, *Paleogaudryina varsoviensis* (Bielecka et Pożaryski), *Saracenaria cornucopiae* (Schwager) ([Fig. 17F, G](#)), *Spirillina infima* (Strickland), *Marginulinopsis buskensis* (Bielecka et Pożaryski) ([Fig. 17Y, Z](#)), *Tristix suprajurassica* (Paalow) and *Eoguttulina inovroclaviensis* (Bielecka et Pożaryski). Marly facies often contain agglutinated foraminifers of the genus *Ammobaculites*: *A. infrajurensis* (Terquem) ([Fig. 17H](#)), *A. coprolithiformis* (Terquem) ([Fig. 17I](#)) and *A. braustei* Cushman et Appland. Starting from the Platynota Zone, and then in the Hypselocyclum and Divisum zones, foraminiferal assemblages become richer of both taxa and individuals. In the upper Lower Kimmeridgian carbonates of central and eastern Poland (Calcareous–Marly–Coquina Formation) and in deposits of northwestern and partly northern area of the Polish Lowlands (Brda Formation; see [Niemczycka, 1997](#)), the most frequent taxa include *Quinqueloculina*

KIMMERIDGIAN					STAGES
LOWER					SUBSTAGES
Bimammatum	Planula	Platyota	Hypselocyclus	Divisum	Standard ammonite zonation
					Foraminifera
					<i>Soccorhisa ramosa</i> (Brady)
					<i>Nubeculinella infraoolithica</i> (Terquem)
					<i>Guttulina jurassica</i> (Gümbel)
					<i>Patelinella cristinae</i> Bielecka
					<i>Paalzowella turbinella</i> (Gümbel)
					<i>Paalzowella feifeli elevata</i> (Paalzow)
					<i>Falsopalmula deslongchampsii</i> (Terquem)
					<i>Spirillina tenuissima</i> Gümbel
					<i>Saracenaria cornucopiae</i> (Schwager)
					<i>Dentalina jurensis</i> (Gümbel)
					<i>Paalzowella feifeli seiboldi</i> Lutze
					<i>Discorbis speciosus</i> Dain
					<i>Astacolus folium</i> (Wiśniowski)
					<i>Lenticulina rotulata</i> (Lamarck)
					<i>Eoguttulina oolithica</i> (Terquem)
					<i>Spirillina polygyrata</i> Gümbel
					<i>Citharina flabellata</i> (Gümbel)
					<i>Spirillina andrea</i> Bielecka
					<i>Planularia beierana</i> (Gümbel)
					<i>Discorbis subspeciosus</i> Bogdanovich et Makarjeva
					<i>Haplophragmoides canui</i> Cushman
					<i>Ammobaculites infrajurensis</i> (Terquem)
					<i>Ammobaculites coprolithiformis</i> (Terquem)
					<i>Ammobaculites brausteyni</i> Cushman et Appland
					<i>Alveosepta jaccardi</i> (Schrodt)
					<i>Pseudolamarckina obliquicamerata</i> Dulub
					<i>Spirillina elongata</i> Bielecka et Pożaryski
					<i>Quinqueloculina jurassica</i> Bielecka et Styk
					<i>Paleogaudryina varsoviensis</i> (Bielecka et Pożaryski)
					<i>Trocholina solecensis</i> Bielecka et Pożaryski
					<i>Spirillina infima</i> (Strickland)
					<i>Marginulinopsis buskensis</i> (Bielecka et Pożaryski)
					<i>Eoguttulina inovroclaviensis</i> (Bielecka et Pożaryski)
					<i>Conorboides marginata</i> Lloyd
					<i>Tristix suprajurassica</i> (Paalzow)
					<i>Epistomina stelicostata</i> Bielecka et Pożaryski
					<i>Fronicularia lingulaeformis</i> Schwager
					<i>Marginulinopsis striatocostata</i> (Reuss)
					<i>Citharina zaglobensis</i> (Bielecka et Pożaryski)
					<i>Triplasia althoffi jurassica</i> (Mjatiuk)
					<i>Citharina paralella</i> (Bielecka et Pożaryski)
					<i>Lenticulina vistulae</i> (Bielecka et Pożaryski)
					<i>Lenticulina infravolgaensis</i> (Furssenko et Polenova)
					<i>Everticyclammina virgullana</i> (Koechlin)
					<i>Tristix temirica</i> (Dain)

Fig. 18. Stratigraphic range charts of foraminifera species from the Lower Kimmeridgian deposits of the Polish Lowlands (central, eastern and part of northern Poland), the Submediterranean standard ammonite zonation as used by [Wierzbowski et al. \(2014\)](#)

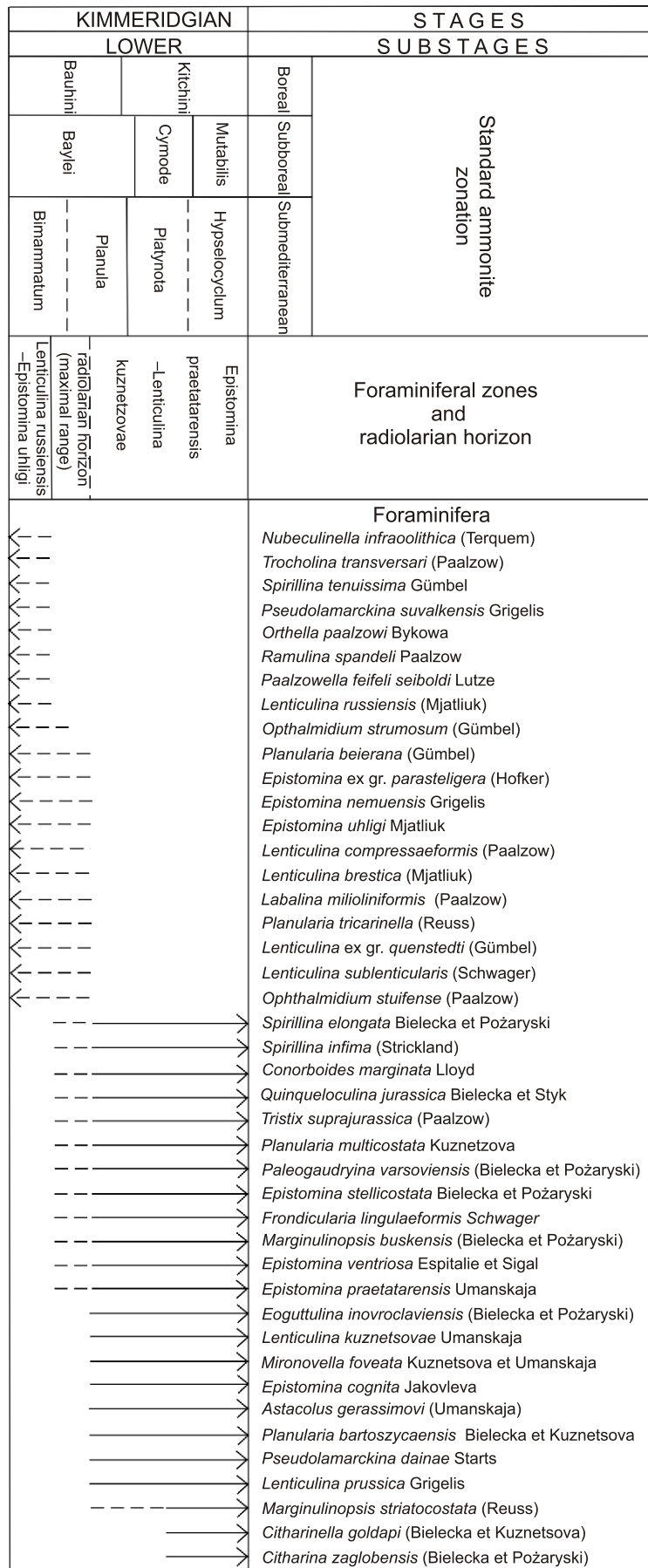


Fig. 19. Stratigraphic range charts of foraminifera species from the Lower Kimmeridgian deposits of the Polish Lowlands (N and NE Poland), correlation of the Boreal and Subboreal ammonite zonations with the Submediterranean zonation as proposed by Wierzbowski et al. (2014, 2015, 2016)

jurassica Bielecka et Styk, *Trocholina solecensis* Bielecka et Pożaryski, *Paleogaudryina varsoviensis* (Bielecka et Pożaryski), *Spirillina infima* (Strickland), *Fronidularia lingulaeformis* Schwager, *Marginulinopsis buskensis* (Bielecka et Pożaryski), *Tristix suprajurassica* (Paalzow), *Eoguttulina inovroclaviensis* (Bielecka et Pożaryski) (Fig. 17L), *E. stellcostata* Bielecka et Pożaryski, *Spirillina elongata* Bielecka et Pożaryski, *Conorboides marginata* Llyod, *Marginulinopsis striatocostata* (Reuss) (Fig. 17Aa), *Citharina zaglobensis* (Bielecka et Pożaryski) (Fig. 17W, X), *C. parallela* (Bielecka et Pożaryski) (Fig. 20A) and *Triplasia althoffi jurassica* (Mjatiuk) (Fig. 17M, N). Besides these characteristic species, the Lower Kimmeridgian of central, eastern, northwestern and partly northern Poland contains cosmopolitan species with long age ranges. The most common taxa are *Astacolus varians* (Bornemann), *A. folium* (Wiśniowski), *Lenticulina brueckmanni* (Mjatiuk), *L. subalata* (Reuss), *L. prima* (d Orbigny), *Planularia tricarinnella* (Reuss), *Eoguttulina oolithica* (Terquem), and others. At the end of the Lower Kimmeridgian (Divisum Zone), a few new species have their first occurrences, e.g. *Lenticulina vistulae* (Bielecka et Pożaryski) (Fig. 20L), *L. infravolgaensis* (Fuessenko et Polenova) (Fig. 20M), *Everticyclammina virguliana* (Koechlin) (Fig. 20G) and *Tristix temirica* (Dain) (Fig. 20F).

FORAMINIFERAL ASSEMBLAGES: NORTHEASTERN POLAND (PERIBALTIC SYNECLISE)

The Early Kimmeridgian of NE Poland (Peribaltic Syncline), like the Oxfordian, was a time of terrigenous-calcareous deposition of the Łyna Formation (see Niemczycka, 1997). The deposits contain foraminiferal assemblages different from those in other areas of the Polish Lowlands.

In the Peribaltic Syncline, the Oxfordian *Lenticulina russiensis*–*Epistomina uhligi* foraminiferal Zone (Grigelis, 1982) terminates its stratigraphic age in the lowermost Lower Kimmeridgian. Upper boundary of this zone correlates with the lowermost part of the Bauhini Zone and the Baylei Zone (Smoleń and Wierzbowski 2012; Fig. 19).

Deposits of the *Lenticulina russiensis*–*Epistomina uhligi* Zone are overlain by a level with radiolarians (“radiolarian horizon”) and depleted foraminiferal assemblages. It contains single Kimmeridgian foraminifera species, including *Trocholina solecensis* Bielecka et Pożaryski (Fig. 17R1, R2), *Spirillina infima* (Strickland) (Fig. 17S), *Conorboides marginata* Lloyd (Fig. 17T1, T2), *Quinqueloculina jurassica* Bielecka et Styk, *Tristix suprajurassica* (Paalzow) (Fig. 17Bb), *Planularia multicostata* Kuznetzova (Fig. 20C, D), *Paleogaudryina varsoviensis* Bielecka et Pożaryski (Fig. 17K), *Epistomina stellcostata* Bielecka et Pożaryski (Fig. 17Q1, Q2), *E. praetariensis* Umanskaja (Fig. 20N1, N2) and *E. ventriosa* Espitalie et Sigal. Foraminiferal assemblages of the upper Lower Kimmeridgian are much richer in both species and individuals. Taxonomic analysis of these assemblages has allowed distinguishing the *Epistomina praetariensis*–*Lenticulina kuznetzovae* Zone (Grigelis, 1982; Fig. 19), established earlier in the remaining areas of the Peribaltic Syncline in the European part of Russia and in Lithuania (e.g., Grigelis, 1982, 1985; Mesezhnikov et al., 1989; Ustinova, 2012). In view of the ammonite stratigraphy revision carried out recently for the Peribaltic Syncline in northeastern Poland (Wierzbowski et al.,

2015), the *Epistomina praetariensis*–*Lenticulina kuznetzovae* zone corresponds to the Bauhini Zone (except its basal part) to the Kitchini Zone of the Lower Kimmeridgian. Because of the presence of ammonite faunas from various palaeogeographic provinces in the Peribaltic Syncline, the Boreal Bauhini Zone is correlated here with the Sub-Boreal Baylei Zone and with the Sub-Mediterranean zones of Bimmamatum and Planula. The Boreal Kitchini Zone corresponds to the Subboreal zones of Cymodoce and Mutabilis and to the Submediterranean zones of Platynota and Hypselocyclum (Fig. 19). The lower part of the *Epistomina praetariensis*–*Lenticulina kuznetzovae* foraminiferal zone, which corresponds possibly to the radiolarian horizon, has a poor assemblage of foraminifers and is difficult for unequivocal interpretation.

In the *Epistomina praetariensis*–*Lenticulina kuznetzovae* Zone, the most common species (including those indicative of the zone) show a Boreal-Atlantic character, among others: *Epistomina praetariensis* Umanskaja, *E. ventriosa* Espitalie et Sigal, *E. cognita* Jakovleva (Fig. 20O), *Lenticulina kuznetzovae* Umanskaja (Fig. 20H, I), *L. prussica* Grigelis (Fig. 20J, K), *Mironovella foveata* Kuznetzova et Umanskaja (Fig. 20P), *Planularia multicostata* Kuznetzova, *Astacolus gerassimovi* (Umanskaja), *Planularia bartoszycaensis* Bielecka et Kuznetzova (Fig. 20E), *Pseudolamarckina dainae* Startseva (Fig. 20R) and *Citharinella goldapi* (Bielecka et Kuznetzova) (Fig. 20B). However, there are also other characteristic species, e.g. *Fronidularia lingulaeformis* Schwager, *Quinqueloculina jurassica* Bielecka et Styk, *Tristix suprajurassica* (Paalzow), *Planularia beierana* (Terquem), *Spirillina elongata* Bielecka et Pożaryski, *Conorboides marginata* Llyod, *Marginulinopsis striatocostata* (Reuss), *Trocholina solecensis* Bielecka et Pożaryski, *Paleogaudryina varsoviensis* Bielecka et Pożaryski, *Epistomina stellcostata* Bielecka et Pożaryski, and others having southern affinities. The character of the faunas described strongly suggests that, during Early Kimmeridgian time, the Peribaltic Syncline constituted the main marine connection between the Boreal and Submediterranean seas of Europe.

CONCLUSIONS

This article provides a biostratigraphic approach to data on the most important foraminifera species found in Middle and Upper Jurassic (Oxfordian and Lower Kimmeridgian) deposits of extra-Carpathian Poland.

1. The proposed scheme of ranges of index foraminifera species is presented in relation to the currently used standard ammonite zonations.

2. Based on the detail study of foraminifers in the Oxfordian and Lower Kimmeridgian deposits, the different foraminiferal assemblages were distinguished with reference to the lithofacies in the individual parts of the Polish Basin and varying influences of the palaeogeographical provinces (characteristic of carbonates of the so-called Sponge Megafacies, and of the Łyna Formation clastic deposits).

3. Additionally, based on the vertical succession of foraminiferal species found in Oxfordian and Lower Kimmeridgian deposits of the Łyna Formation in NE Poland, the foraminiferal zones of *Ophthalmidium sagittum*–*Epistomina volgensis*, *Ophthalmidium strumosum*–*Lenticulina brestica*, and *Lenticulina russiensis*–*Epistomina uhligi* and *Epistomina*

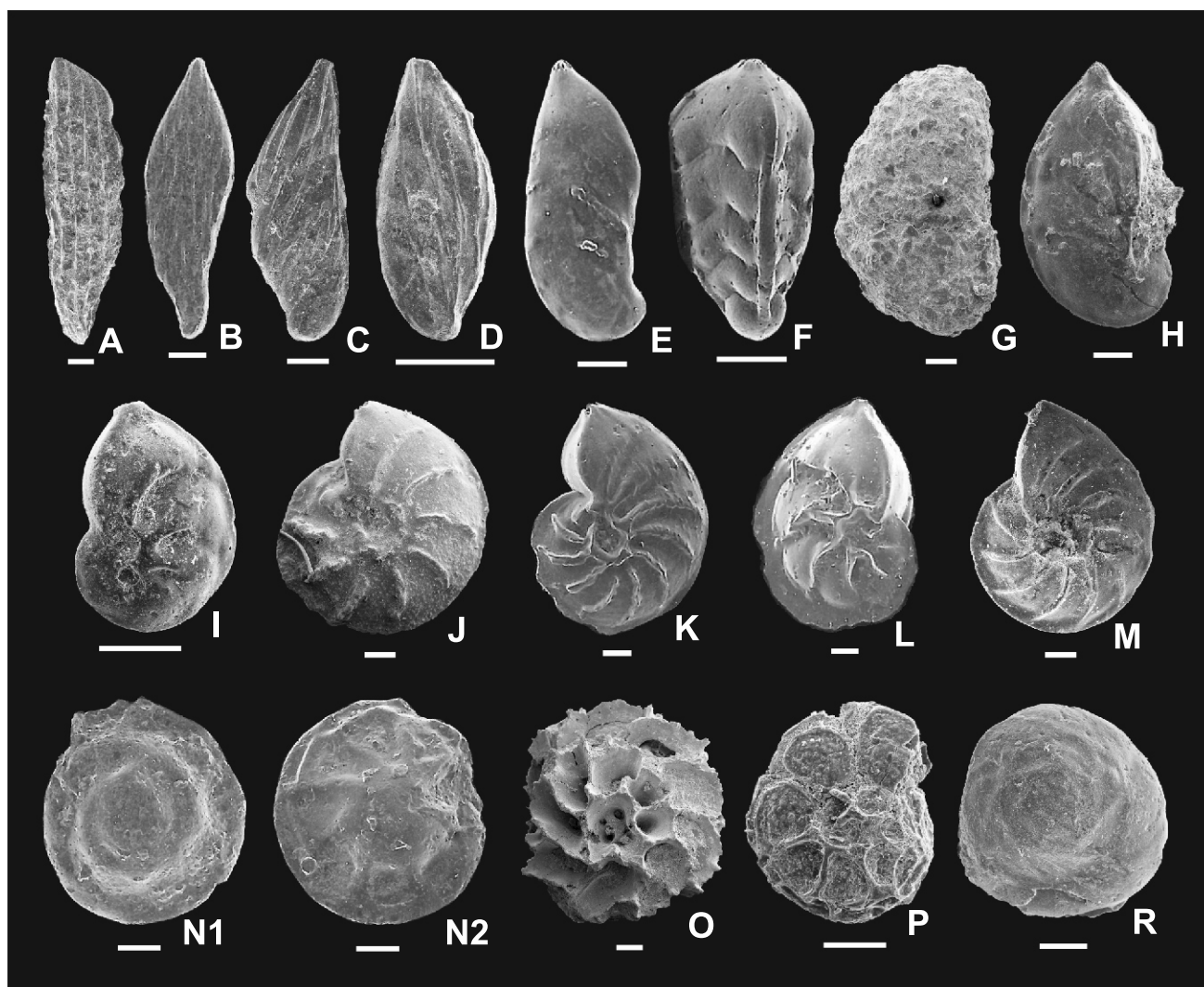


Fig. 20. Foraminifers from Lower Kimmeridgian carbonates of the Polish Lowlands (A, F, G, L, M) and Lower Kimmeridgian marly deposits of the Łyna Formation (*Epistomina praetatarensis*–*Lenticulina kuznetsovae* Zone) of NE Poland (B–E, H–K, N1–R)

A – *Citharina paralella* (collection of Smoleń, 2015); B – *Citharinella goldapi* (collection of Smoleń, 2015); C, D – *Planularia multicostata* (collection of Smoleń, 2015); E – *Planularia bartoszycaensis* (collection of Smoleń, 2015); F – *Tristix temirica* (collection of Smoleń, 2015); G – *Everticyclammina virguliana* (collection of Bielecka and Styk, 1980); H, I – *Lenticulina kuznetsovae* (collection of Smoleń, 2015); J, K – *Lenticulina prussica* (collection of Smoleń, 2015); L – *Lenticulina vistulae* (collection of Smoleń, 2015); M – *Lenticulina infravolgaensis* (collection of Smoleń, 2015); N1 – *Epistomina praetatarensis*, dorsal side (collection of Smoleń, 2015); N2 – *Epistomina praetatarensis*, ventral side (collection of Smoleń, 2015); O – *Epistomina cognita* (collection of Smoleń, 2015); P – *Mironovella foveata* (collection of Smoleń, 2015); R – *Pseudolamarckina dainae* (collection of Smoleń, 2015); scale bars – 100 µm

praetatarensis–*Lenticulina kuznetsovae* are characterized following the original authors' descriptions.

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