The oldest stage of the Outer Carpathian evolution in the light of Oxfordian–Kimmeridgian exotic clast studies (southern Poland)

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Abstract

In the Late Jurassic, the rifting process led to the disintegration of the southern margin of the North European Platform and to the opening of the Outer Carpathian flysch basin sedimentary system. The initial sediments accumulated in the northern part of the basin are related to both the destruction and resedimentation of older platform deposits. Since the sedimentary succession of this pre-flysch phase was consumed by the Miocene subduction, its only traces are represented, nowadays, by clasts preserved as exotics in the succeeding flysch deposits. Our analysis of foraminifers as well as calcareous and organic dinoflagellate cysts found in these exotics confirms the Oxfordian–early Kimmeridgian timing of the platform phase that preceded the opening of the flysch basin. The exotics are represented by three main facies types: sponge–microbial limestones, oncoid–intraclastic–*Crescentiella* limestones and fine-grained, biodetrital limestones with *Saccocoma*. These deposits are related to mid-ramp to outer-ramp settings. The land influence was rather weak, and these sedimentary settings were dominated by pelagic/hemipelagic accumulation. The studied facies are similar to facies types widely distributed over the northern shelf area of the Western Tethys (e.g., extra-Carpathian southern Poland, Carpathian Foredeep basement, southern Germany). In turn, coeval strata known from the part of the Magura Basin and of the Penninic–Pieninic Ocean, which were situated in more southern part of the Tethys, yielded different microfacies reflecting significant differences between the sedimentary settings of the study area and its southern extensions.

Keywords Upper Jurassic · Facies/microfacies · Microfossils · Palynology · Paleogeography · Outer Carpathians

Introduction

The uppermost Jurassic deposits, although fragmentarily preserved due to a high tectonic engagement, are well known from the Outer Carpathian outcrops. This contrasts both the underlying platform strata and the deposits from the margins and intrabasinal ridges, which were either eroded or consumed during the Miocene subduction (Książkiewicz

1956b, 1977). The only remnants of the latter are crystalline and sedimentary clasts—i.e., the “exotics” (Hohenegger 1861), which are also the only evidence of the sedimentation mode that preceded the opening of the Carpathian flysch basins and which later proceeded along their margins. Studies on exotics allow to reconstruct the paleogeography as well as the geological and the sedimentological history of the destroyed parts of the Carpathian basins and their surroundings (e.g., Nowak 1927; Książkiewicz 1931, 1965).

The exotics occur in various lithostratigraphic units of the Outer Carpathians. They show various dimensions: from large blocks, several tens of meters across, which form isolated klippen, e.g., in the Štramberg (Czech Republic) and in the Andrychów (Poland) areas, to relatively common, pebble- and cobble-sized clasts. The most common and the best recognized exotics in the Polish Outer Carpathians are the remnants of Tithonian–lowermost Cretaceous, shallow-water carbonate platform deposits (the so-called Štramberg-type limestones; for an overview, see Kołodziej 2015). Other examples are Tithonian pelagic limestones as well as

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Devonian, Carboniferous, Cretaceous, and Paleogene carbonate rocks (e.g., Nowak 1927; Książkiewicz 1956b; Oszczytko 1975; Burtan et al. 1984; Mišík et al. 1991; Rajchel and Myszkowska 1998; Oszczytko et al. 2006; Olszewska et al. 2011).

The clasts of Oxfordian–Kimmeridgian calcareous rocks, which were deposited just prior to and during the opening of the proto-Silesian Basin, are also known from the Outer Carpathians. They were observed by, e.g., Nowak (1927), Książkiewicz (1931), Burtan et al. (1984), and Matyszkiewicz and Słomka (2004), but their more detailed studies are limited mainly to the Bachowice exotic blocks and the Andrychów Klippes (e.g., Książkiewicz 1956a; Nowak 1976; Olszewska and Wieczorek 2001; Olszewska et al. 2011). As this age range is crucial to the reconstruction of the paleogeography and sedimentary conditions of the early stages of the Carpathian basin development, we investigated Oxfordian–Kimmeridgian exotic carbonate clasts from the Polish Outer Carpathians. Following a preliminary description of the Oxfordian–Kimmeridgian clasts from two localities in the Beskid Mały Mts. included in Strzeboński et al. (2017), we present here the detailed micropaleontological, palynological and microfacies study of exotics coming from these two localities as well as 10 additional sites in the western part of both the Silesian and Subsilesian units of the Polish Outer Carpathians. Our results are compared with the epicontinental deposits from the northern margin of the Carpathian basins known from both outcrops and boreholes. The Oxfordian–Kimmeridgian paleogeographical background is also presented, in accordance with the contemporary interpretations.

Geology

Geological background

In the Late Jurassic, an important phase of plate reorganization took place in the Tethyan–Alpine domain. A rifting process disintegrated the southern margin of the North European Platform composed of the Precambrian crystalline basement and the Paleozoic–Mesozoic sedimentary cover (e.g., Birkenmajer 1988; Olszewska and Wieczorek 2001; Golonka 2004; Golonka et al. 2000, 2006; Aubrecht and Szulc 2006). It resulted in the opening of new basins in the latest Jurassic–Miocene that formed the northernmost, peripheral part of the western Tethyan Ocean. In our study area, the rifting-related break-up of the carbonate platform led to the formation of the NW–SE-elongated, Outer Carpathian Severin–Moldavide Basin (Balintoni 1998), also called the proto-Silesian Basin (e.g., Golonka et al. 2008a). The new basins were separated by ridges built of the relics of the North European Platform, e.g., the Baška–Inwałd

Ridge and the Silesian Ridge (e.g., Książkiewicz 1965; Matyszkiewicz and Słomka 2004; Golonka et al. 2008a). The narrow Bachowice Basin is supposed to be situated north of the proto-Silesian Basin and the Baška–Inwałd Ridge (Książkiewicz 1956a). The proto-Silesian basin evolved subsequently into the Outer (Flysch) Carpathian sub-basin system, which included the Silesian, the Subsilesian, and the Skole basins, bordered on the south by the Silesian Ridge that separated them from the largest Outer Carpathian Magura Basin.

The timing of this carbonate platform break-up can be deduced from dating of the oldest deposits accumulated in the flysch basins. These are dark marly shales and, subordinately, pelitic and detrital limestones of the Vendryně Formation (after Eliáš et al. 2003), formerly known as the Lower Cieszyn Shale (after Hohenegger 1861). Their deposition began presumably in the latest Kimmeridgian/earliest Tithonian (Olszewska et al. 2008) but they are mostly of Tithonian age (Skupien and Smaržová 2011; Skupien and Doupovcová 2019; Salamon et al. 2019), although the former Czech literature did not exclude the older (even Oxfordian) age of these beds based on ammonites (Vašíček 1972). They are overlain by uppermost Tithonian–lowermost Cretaceous calciturbiditic deposits (Cieszyn Limestone or Cieszyn Limestone Formation), and the Upper Cieszyn Shale (Cisownica Shale Member of the Hradiště Formation after Golonka et al. 2008b). In the Early Cretaceous, when erosion reached the crystalline basement, the siliciclastic flysch sedimentation has begun.

Geological setting

The study area is located in the western sector of the Outer (Flysch) Carpathians, southern Poland, between the Soła and the Dunajec rivers, in the Beskidian Foothills and the Beskidy Mts. Range. Tectonically, the study area represents the western part of the Silesian and Subsilesian nappes, bordered to the south by the Magura Nappe—the largest nappe of the Outer Carpathians (Fig. 1). To the north, both nappes are thrust over the autochthonous and the folded Miocene strata (Stebnik and Zgórbice units) of the Carpathian Foredeep. The uppermost Jurassic–Miocene succession of the Silesian Unit is built mainly of flysch deposits (Fig. 2). The Subsilesian Unit, in turn, represents the Lower Cretaceous–Miocene sequence deposited under shallower conditions than the Silesian Unit, possibly on the slope of the Subsilesian Ridge (e.g., Ślaczka et al. 2006), which developed at the end of the Early Cretaceous (e.g., Książkiewicz 1965; Golonka et al. 2000).

Fig. 1 Position of the study area against the tectonic map of the Polish Carpathians and their foreland (map after: Żytka et al. 1989; Cieszkowski et al. 2009). Sites: S1—Roztoka, S2—Miłówka, S5—

Lanckorona, S9—Kobylec, S10—Krzyworzeka, S13—Sułów, S15—Trąbki, S16—Biskupice, S19—Gródek nad Dunajcem, S28—Mały Czaniec, S29—Mucharz, S30—Targoszów

Materials and methods

The studied exotics come from Lower Cretaceous to Eocene strata (Fig. 2, Table 1) exposed at 12 sites (Fig. 1) distributed along stream and lake banks (Fig. 3). In these outcrops, the calcareous exotics are represented by Tithonian–Berriasian limestones (mainly Štramberg-type limestones), Oxfordian–Kimmeridgian limestones, and, only occasionally, by Paleogene and Paleozoic carbonates (Kowal-Kasprzyk 2016). The Oxfordian–Kimmeridgian clasts are less common than the Tithonian–Berriasian ones; the former were absent in 19 of 31 sites studied by Kowal-Kasprzyk (2016). The exceptions are two localities in the Beskidy Range (sites: Mucharz—S29, and Targoszów—S30) where the Oxfordian–Kimmeridgian calcareous clasts are common; whereas, the Štramberg-type exotics are relatively rare (see also Strzeboński et al. 2017).

The samples were analyzed macro- and microscopically. Microfossils and microfacies were studied in standard thin

sections under the polarizing microscope equipped with digital camera. Totally, 30 samples of all the analyzed pebbles and cobbles (a few up to 25 cm in size) were identified as the Oxfordian–Kimmeridgian rocks and were used in our study (Table 2; see also Electronic Supplementary Material) (samples from sites S29 and S30 were also used by Strzeboński et al. 2017). Additionally, the 18 exotic clasts were selected for palynological studies (Table 2). They were subjected to relevant sample preparation including the removal of carbonates (with HCl) and silicates (with HF), sieving on 15- μ m mesh nylon sieve, and heavy liquid separation. No oxidation was applied. Palynological slides (with glycerine jelly as a mounting medium) were examined under the Axiolab Zeiss microscope (100 $\times$ oil lens); photomicrographs were taken using the Sony DSC-75 camera. The biostratigraphy was based on known ranges of foraminifera as well as calcareous and organic-walled dinoflagellate cysts. The thin sections are stored in the University of Sciences and Technology (Kraków), and the palynological residues and

Fig. 2 Generalized lithostratigraphic column of the Silesian Unit (a) (after Cieszkowski et al. 2009, modified) and the lower part of the generalized lithostratigraphic column of the Subsilesian Unit (b) (after e.g., Ślaczka et al. 2006, modified) with marked position of the studied exotics

slides are stored in the collection of the Institute of Geological Sciences, Polish Academy of Sciences (Kraków).

Results

Facies and microfacies analysis

The studied exotics represent three facies types (FT 1–3): (i) light-beige, porous, sponge–microbial limestones (FT 1), (ii) beige, nonporous, oncoid–intraclastic–*Crescentiella* limestones (FT 2) and (iii) dark-gray, fine-grained, biotrital limestones with *Saccocoma* (FT 3) (Figs. 4, 5; Table 3; see also Electronic Supplementary Material).

FT 1: sponge–microbial limestones

The first facies type—sponge–microbial limestones (FT 1)—comprises limestones with numerous dish-shaped sponges and/or fine-grained bioclastic limestones (Fig. 4a–c). The FT 1 facies includes two main types of microfacies: (i) sponge–microbial framestones–floatstones (Fig. 4a, b) and (ii) fine-grained bioclastic wackestones–packstones (Fig. 4c). The first microfacies type embraces calcified siliceous sponges (Lithistida and Hexactinellida) onto which clotted thrombolites (Fig. 4a) or, less frequently, micritic stromatolites grew (cf. Schmid 1996; Riding 2000). Growth cavities as well as borings geopetally filled with partly silicified internal sediments are common. Tuberooids of diameters up to 1.7 cm are abundant as well as microencrusting organisms, usually bryozoans, foraminifers (*Nubecularia*, *Bullopore*; see Fig. 6a), serpulids and agglutinating annelids *Terabella lapilloides* (Fig. 6b). Some samples are enriched with individual forms of *Crescentiella morronensis* (*incertae sedis*; e.g., Senowbari-Daryan et al. 2008; Pleš et al. 2017; Krajewski and Schlagintweit 2018) (Fig. 6c).

The second microfacies type comprises fine-grained bioclastic wackestones or packstones composed mostly of peloids, brachiopods, spicules, foraminifers, calcareous dinocysts (Fig. 7), crinoids, recrystallized radiolarians, echinoids, as well as bivalves, gastropods, ophiuroid ossicles, zoospores *Globochaete alpina*, ostracod carapaces, fragments of ammonites as well as numerous tuberooids and bioclasts (Fig. 4c). Foraminifers are represented by calcareous (*Cornuspira*, *Spirillina*, *Lenticulina*, *Protopeneroplis*, *Rumano-lina*, Epistominidae, nodosarids, *Ophthalmidium* and less common other miliolids; see: Fig. 6d–j) and agglutinated

Table 1 Localities of studied outcrops (lithostratigraphy after Bieda et al. 1963, modified)

Name and symbol of the locality	Tectonic unit	Lithostratigraphy	Coordinates
Roztoka (S1)	Silesian	Hradiště Formation—Piechówka Sandstone Member	49° 52' 6.14" N; 20° 48' 4.18" E
Miłówka (S2)	Silesian	(Hauterivian–Aptian)	49° 54' 54.1" N; 20° 46' 47.2" E
Lanckorona (S5)	Subsilesian		49° 50' 26.3" N; 19° 44' 23.5" E
Sulów (S13)	Silesian		49° 57' 10.8" N; 20° 06' 42.6" E
Biskupice (S16)	Silesian		49° 57' 30.2" N; 20° 07' 01.5" E
Trąbki (S15)	Subsilesian	Geize Beds (Albian–Cenomanian)	49° 57' 33.2" N; 20° 08' 03.2" E
Kobylec (S9)	Silesian	Istebna Formation—Lower Istebna Beds (Campanian–Maas-	49° 53' 13.8" N; 20° 16' 57.0" E
Krzyworzeka (S10)	Silesian	trichtian)	49° 52' 06.4" N; 20° 08' 37.7" E
Mały Czaniec (S28)	Silesian	Istebna Formation—Upper Istebna Beds (Paleocene)	49° 51' 38.8" N; 19° 15' 46.7" E
Mucharz (S29)	Silesian		49° 49' 15.9" N; 19° 32' 33.1" E
Targoszów (S30)	Silesian		49° 45' 17.2" N; 19° 27' 35.3" E
Gródek nad Dunajcem (S19)	Silesian	Ciężkowice Formation (Upper Paleocene–Eocene)	49° 43' 56.8" N; 20° 43' 17.2" E

Fig. 3 Examples of outcrops with studied exotics (photo: J. Kowal-Kasprzyk). **a** Mucharz (S29), conglomerate with exotics, Istebna Formation, Upper Istebna Beds. **b** Gródek nad Dunajcem (S19), weathered surface of conglomerate with exotics, Ciężkowice Formation

forms (such as *Protomarssonella*, *Eomarssonella*, *Reophax* and *Ammobaculites*; see: Fig. 6k, l), and rare planktonic forms (“globuligerinids”; see: Fig. 6m, n) encountered only in some samples. Sometimes, thin leiolites (sensu Schmid 1996) can be observed. Silicification is frequent in bioclastic wackestones–packstones as impregnations of microcrystalline quartz (cf. Matyszkiewicz et al. 2015). In most cases, the matrix is silicified; whereas the grains remain unaltered. In the framestones, the silicification is poor.

FT 2: oncoid–intraclast–*Crescentiella* limestones

The oncoid–intraclast–*Crescentiella* limestones (FT 2) represent a facies dominated by detrital limestones composed mainly of various coated grains, intraclasts, bioclasts and numerous *Crescentiella* specimens. The microfacies types include: (i) oncoid–intraclast floatstones–wackestones and

(ii) *Crescentiella*–peloidal wackestones, also bindstones (less commonly) (Fig. 4d–f). The first microfacies consists of abundant, small, oval oncoids, usually up to 1 mm in diameter (type I, rarely type II; e.g., Flügel 2004; Vedrine et al. 2007), cortoids and irregular intraclasts, up to 3 mm across (Fig. 4f). The surfaces of subangular intraclasts are commonly coated by microbial envelopes. Frequent are aggregate grains with cores built of peloids, micritic ooids and bioclasts (Fig. 4d). Among bioclasts small bivalves, foraminifers, gastropods, crinoids, bryozoans, echinoids, calcareous dinocysts (Fig. 7) and calcareous sponges are abundant whereas siliceous sponges are less frequent. Ostracod carapaces, ophiuroid ossicles, and *G. alpina* also appear.

The second microfacies comprises numerous individual specimens of *Crescentiella* sometimes connected with microbial crusts, peloids and small bioclasts. Some *Crescentiella* specimens are up to 1.2-cm high. In the studied

Table 2 List of studied exotic samples including facies types, results of palynological analysis and age (based on microfossil assemblages and, in some samples, calcareous dinoflagellate assemblages)

Sample	Facies type	Palynological analysis	Age of the sample
S1/5	FT 1	–	Oxfordian
S2/8	FT 1	–	Oxfordian
S5/13	FT 1	+ (Barren)	Lowest Kimmeridgian
S9/6	FT 3	+ (Barren)	(Upper?) Oxfordian–lowest Kimmeridgian
S10B/10	FT 1	+ (Poor)	Oxfordian–Kimmeridgian
S13/4	FT 1	–	(Upper?) Oxfordian–Kimmeridgian
S13/5	FT 2/FT 1	+ (Barren)	Kimmeridgian
S13/6	FT 2	–	Oxfordian–lowest Kimmeridgian
S13/7	FT 1	–	(Upper?) Oxfordian–lowest Kimmeridgian
S15/1	FT 1	–	Oxfordian–lower Kimmeridgian
S16/11	FT 2/FT 1	–	Oxfordian–lower Kimmeridgian
S19/20	FT 1	+	Middle Oxfordian–lower Kimmeridgian
S19/32	FT 1	+ (Poor)	(Upper?) Oxfordian–lowest Kimmeridgian
S28/5	FT 1	+ (Barren)	Middle Oxfordian–lower Kimmeridgian
S29/1	FT 1	–	Lower Kimmeridgian
S29/3	FT 2	–	(Upper?) Oxfordian–lower Kimmeridgian
S29/4	FT 3	–	Close to the Kimmeridgian/Tithonian boundary
S29/5	FT 1	–	(Upper?) Oxfordian–lowest Kimmeridgian
S29/7	FT 1	+ (Barren)	(Upper?) Oxfordian–lowest Kimmeridgian
S29/11	FT 3	+ (Barren)	Lowest Kimmeridgian
S29/12	FT 1	+ (Barren)	Oxfordian–lowest Kimmeridgian
S29/14	FT 3	+ (Barren)	Oxfordian–Kimmeridgian
S29/15	FT 3	+ (Barren)	Kimmeridgian
S30/1	clasts of FT 2 in FT 3	+ (Barren)	Kimmeridgian
S30/2	FT 1	+ (Barren)	Oxfordian–lower Kimmeridgian
S30/4	FT 3	+	(Upper?) Oxfordian–lowest Kimmeridgian
S30/5	FT 3	+	(Upper?) Oxfordian–lowest Kimmeridgian
S30/7	FT 3	+ (Barren)	Kimmeridgian
S30/9	FT 3	–	Kimmeridgian?
S30/18	FT 1/FT 3	+	Lowest Kimmeridgian

deposits, *Crescentiella* morphotypes are formed by encrustation or symbiosis between nubecularid foraminifers or enigmatic, spar-filled, tube-shaped structures and microbial envelopes (cf. Senowbari-Daryan et al. 2008; Schlagintweit and Gawlick 2008; Pleş et al. 2017; Krajewski and Schlagintweit 2018). Within the *Crescentiella* laminae, foraminifers and fine bioclasts are observed. Among bioclasts, small calcified sponges, gastropods, foraminifers, calcareous dinocysts and echinoids are encountered (Fig. 4e). Foraminifers in FT 2 facies are represented by calcareous (*Lenticulina*, *Spirillina*, *Rumanolina*, *Cornuspira*, *Bullopore*, nodosarids, epistominids, *Ophthalmidium* and other miliolids; see: Fig. 6o, p) prevailing over agglutinated forms (such as *Protomarsionella* and *Textularia*). Less common are planktonic “globuligerinids” (Fig. 6r). In larger extraclasts, fragments of FT 2 sediments occur as clasts within the FT 3 sediments (see FT 3 description). In the FT 2 facies, dolomitization and silicification processes are common. In

the matrix, dolomite forms mainly a dense mosaic of subhedral to anhedral crystals.

FT 3: Fine-grained biotrital limestones with *Saccocoma*

Macroscopic observations reveal that the FT 3 facies—fine-grained biotrital limestones with *Saccocoma*—is represented by gray or dark-gray, pelitic and siliceous–pelitic limestones. Three microfacies types were distinguished: (i) filamentous–*Saccocoma* wackestones, (ii) spicule–*Saccocoma* wackestones and (iii) crinoid–*Saccocoma* packstones–wackestones (Fig. 5).

The first type embraces numerous thin filaments, radiolarians, and fragments of the planktonic crinoid *Saccocoma* sp. onto which the syntaxial calcite cement commonly grows (Fig. 5a, b).

The second microfacies contains numerous bioclasts: calcified sponge spicules and *Saccocoma* fragments but also echinoid plates, radiolarians, ophiuroid ossicles,

Fig. 4 Microfacies from exotic clasts (photo: M. Krajewski). **a** Sponge-microbial floatstone with clotted thrombolite (cT) on the outer part of sponge (Sp), tuberoïd (T), serpulids (arrows) and *Ter-e-bella* (Tr), FT 1, sample S13/4. **b** Sponge-microbial framestone; sponge (Sp) with geopetal infilling in the center and boring (Br) on the left side and growth cavity (Gr), FT 1, sample S28/5. **c** Fine-grained wackestone with numerous tuberoïds (T) and peloids, FT 1,

sample S10B/10. **d** *Crescentiella*-peloidal wackestone, *Crescentiella* (arrows), locally also bindstone (left side) with calcareous sponge (Sp), FT 2, sample S13/6. Intraclastic-oncoid wackestone-framestone with intraclasts (white arrows), echinoids (E), oncoids (On), gastropods (G) and aggregate grains (red arrows), FT 2, samples S13/5 (e) and S16/11 (f)

Fig. 5 Microfacies from exotic clasts (photo: M. Krajewski). **a** Filamentous–*Saccocoma* wackestone with *Saccocoma* (red arrows) and filaments (white arrows), FT 3, sample S30/9. **b** Spicule–*Saccocoma* wackestone, FT 3, sample S29/4. **c** Spicule–*Saccocoma* wackestone–packstone, spicules (red arrows) FT 3, samples S30/4 (c) and S29/15

(d). **e** Crinoid–*Saccocoma* packstone, FT 3, sample S29/14. **f** Polished slab of exotic clast with redeposited clasts of oncoid–intraclast–*Crescentiella* limestone representing FT 2 within fine-grained biode-trital limestone (FT 3), sample S30/1

Table 3 Facies and microfacies types

Facies type	Microfacies	Depositional environment
FT 1: sponge–microbial limestones	Sponge–microbial framestones–floatstones Fine-grained bioclastic wackestones–packstones	Low- to moderate-energy mid ramp
FT 2: oncoid–intraclastic– <i>Crescentiella</i> limestones	Oncoid–intraclast floatstones–wackestones <i>Crescentiella</i> –peloidal wackestones, less commonly also bindstones	Moderate-energy mid ramp
FT 3: fine-grained, biodetrital limestones with <i>Saccocoma</i>	Filamentous– <i>Saccocoma</i> wackestones Spicule– <i>Saccocoma</i> wackestones Crinoid– <i>Saccocoma</i> packstones–wackestones	Low-energy outer ramp

foraminifers, fragments of crinoids and aptychs with microborings (Fig. 5d).

The third microfacies is dominated by various, densely packed fragments of crinoids (Fig. 5e). Foraminifers in FT 3 facies are less diversified compared to both FT 1 and FT 2, and are dominated by calcareous *Spirillina*, *Lenticulina*, *Rumanolina*, *Neotrocholina* and nodosarids (Fig. 6s, t). Agglutinated foraminifers (e.g., *Protomarssonella*; see Fig. 6u) are less common, and planktonic foraminifers appear only occasionally. Calcareous dinocysts (Fig. 7) are numerous, and *G. alpina*, holothurian sclerites and ostracod carapaces are also present. Graded bedding is observed in some samples: crinoid packstones dominate in the bottom part (Fig. 5e) and grade up the sequence into wackestones, rarely to mudstones (Fig. 5c). Sometimes, large exotic clasts contain not only the FT 3 facies but also irregular clasts, 1.5–3-cm thick, formed by oncoid–bivalve–bioclastic grainstones–packstones corresponding to the FT 2 facies (Fig. 5f). The size of the clasts exceeds several centimeters, but some of them can be larger than the exotics. The clasts were deposited orderly, with parallelly arranged longer axes. Based on the position of geopetal infillings in relation to inclination of longer axes of the clasts and the thin bivalve shells in the FT 3 facies, it can be concluded that these deposits were laid down in a slope setting. Some parts of sediments were silicified with cryptocrystalline silica growing mainly in the matrix.

Palynological analysis

From 18 studied exotic clasts, only four yielded palynological organic matter suitable for further studies: S19/20, S30/4, S30/5, and S30/18 (two other samples, S10B/10 and S19/32 yielded very low numbers of poorly preserved dinoflagellate cysts). These four clasts are dark-gray to black, micritic limestones. In contrast to the other clasts, which appeared to be barren, these samples contained high amounts of palynological organic matter composed mainly of dinoflagellate cysts (Fig. 8; for full list of taxa in samples see Electronic Supplementary Material). The remaining barren clasts are mainly light-colored (beige, gray-creamish, pale grayish)

limestones. However, it is noteworthy that some barren clasts are dark-colored limestones (e.g., S9/6, S30/7), identical with the productive ones.

The four productive samples showed similar palynofacies dominated by dinoflagellate cysts and black, opaque phytoclasts. The palynomorphs differ significantly both in preservation and taxonomical composition of the assemblages. The sample S19/20 yielded very well-preserved dinoflagellate cysts with predominating *Systematophora* (*S. areolata*, *S. valensii*, *S. varispinosa*, and *S. vestita*). The three further samples: S30/4, S30/5, and S30/18 yielded similar, slightly worse-preserved specimens than in sample S19/20, assemblages with frequent *Sentusidinium* spp., *Leptodinium subtile* and *Gonyaulacysta jurassica*. Foraminifers organic linings occur in these samples.

Discussion

Age of studied exotics

Calcareous microfossils

Based on the foraminifers and calcareous dinocysts, the age of studied samples can be generally determined as Oxfordian and Kimmeridgian (Table 2; see also Electronic Supplementary Material). Foraminifers and calcareous dinocysts are the biostratigraphically most significant microfossils of studied exotics (Figs. 6, 7). The majority of the identified foraminifers have relatively wide known stratigraphic ranges (after: Olszewska et al. 2011, 2012; Olszewska 2014, and references therein) (Fig. 9); hence, precise age determinations are impossible. The planktonic foraminifers—“globuligerinids”—are typical components of the Oxfordian calcareous rocks in southern Poland, but they can also appear in the Kimmeridgian and the Tithonian. Determination of the planktonic species in thin sections is problematic but the occurrence of specimens, which can be classified as *Globuligerina oxfordiana*, suggests an Oxfordian–earliest Kimmeridgian age (e.g., Olszewska et al. 2011, 2012; Olszewska 2014). “*Compactogerina stellapolaris*” is

Fig. 6 Microfossils, mainly foraminifera, from the exotic clasts (photo: J. Kowal-Kasprzyk). **a** *Bullopore tuberculata* (S16/11). **b** *Terebella lapilloides* (S13/4). **c** *Crescentiella morronensis* with encrustations of nubecularid foraminifer and probably serpulid worms (S10B/10). **d** *Spirillina tenuissima* (S1/5). **e** *Ophthalmidium pseudocarinatum* (S5/13). **f** *Protopeneroplis striata* (S5/13). **g** *Ophthalmidium bolgradensis* (S2/8). **h** *Spirillina andreae* (S5/13). **i** *Ophthalmidium strumosum* (S19/32). **j** *Spirillina elongata* (S5/13). **k** *Eomarssonella paraconica* (S2/8). **l** *Ammobaculites irregularis* (S13/7). **m** *Globuligerina oxfordiana* (S29/7). **n** *Globuligerina oxfordiana* (S30/18). **o** *Rumanolina feifeli seiboldi* (S13/6). **p** “*Cornuspira eichbergensis*” (S29/3). **r** “*Compactogenerina stellipolaris*” (S30/1). **s** *Rumanolina feifeli feifeli* (S30/5). **t** *Neotrocholina valdensis* (S29/4). **u** *Protomarssonella jurassica* (S9/6)

observed in the Kimmeridgian rocks from southern Poland, but it should be mentioned that Gradstein (2017) supposes a Late Cenozoic age of its holotype; thus, the Jurassic forms should be revised and they cannot be treated as a valid stratigraphic marker.

The calcareous dinocysts, common in the studied samples (Fig. 7), can also be used for stratigraphy, but it must be noted that their ranges may vary between various sedimentary basins; hence, the widest known ranges (after Borza 1969; Řehánek and Cecca 1993; Řehánek and Heliasz 1993; Řeháková 2000; Olszewska 2014; Olszewska et al. 2011, 2012 and references therein) are here applied.

Organic-walled dinoflagellate cysts

The most probable age of the organic-walled dinoflagellate cysts assemblages from the four productive samples is middle Oxfordian to earliest late Kimmeridgian. The majority of determined organic-walled dinoflagellate cysts occurs in the Upper Jurassic deposits, mainly in the Oxfordian–Kimmeridgian (see Table 2 and Fig. 9). The lower age range of the studied samples is defined by the occurrence of *Leptodinium subtile*, *Endoscrinium luridum*, and *Glossodinium dimorphum*. The oldest occurrences of these species are known from the lower and middle Oxfordian of the Boreal Realm from the lowermost Oxfordian *Cordatum* Ammonite Zone (*L. subtile*), the lower middle Oxfordian *Densiplicatum* Ammonite Zone (*E. luridum*), and the upper middle Oxfordian *Tenuiserratum* Ammonite Zone (*G. dimorphum*; Riding and Thomas 1992). The upper range, in turn, can be determined by the presence of a few species that are the most common in the uppermost lower Kimmeridgian to lower upper Kimmeridgian ammonite zones *Autissiodorensis* and *Elegans*: *E. luridum*, *Gonyaulacysta jurassica*, and *Rhynchodiniopsis cladophora* (Riding and Thomas 1992).

The above-described assemblages allow us to correlate the productive exotics with the *Scriniodinium crystallinum* and/or *Endoscrinium luridum* dinoflagellate cyst zones. These zones were established in the North Sea Basin (Woolam and Riding 1983, subsequently emended by Riding and

Thomas 1988 and Poulsen 1991). Poulsen (1992, 1993, 1996) successfully applied this zonal scheme also in Poland based on similarity of coeval assemblages from central and southern (but not southernmost) Poland (i.e., in the area between the Subboreal and the Submediterranean provinces). Among the dinoflagellate cyst assemblages described by this author from Poland, the most similar ones compared to those found in the exotics are species correlated with the Subzone c of the *Scriniodinium crystallinum* Zone (i.e., the uppermost Oxfordian *Rosenkrantzi* Ammonite Zone). The communities are dominated by *Systematophora areolata*, *Gonyaulacysta jurassica*, and *Sentusidinium rioultii*, with frequent *Epiplosphaera* and *Rhynchodiniopsis cladophora* (Poulsen 1991). Assemblages from the younger strata in Poland (*Hypselocylcum-Divisum* zones) not only include most of the species found in the exotics, but also they contain characteristic and frequent specimens of *Cribroperidinium* and *Subtilisphaera? inaffecta* that are absent from the exotics. Frequent *Cribroperidinium* (*C. venustum*) associated with *Escharisphaeridia mantellii*, *Atlantodinium jurassicum* and *Amphorula dodekovae* (all missing in the exotics) were described from the lower Kimmeridgian strata of the surroundings of the Holy-Cross Mountains (Gedl and Ziája 2004).

Paleoenvironment

Facies interpretation

The studied facies are related to mid-ramp to outer-ramp settings. Usually, on the northern Tethys shelf, the Oxfordian–Kimmeridgian sponge–microbial limestones (FT 1) are interpreted as distal mid-ramp facies, i.e., deposited mostly in a low-energy, nutrient-rich environment. The FT 1 formed at estimated depths of some tens of meters, between the fair-weather and the storm waves bases (e.g., Keupp et al. 1993; Leinfelder et al. 1996; Olóriz et al. 2003; Olivier et al. 2003; Reolid et al. 2005; Matyszkiewicz et al. 2006, 2012; Krajewski et al. 2016, 2018; Olchowcy et al. 2019).

The oncoid–intraclast–*Crescentiella* limestones (FT 2) dominated by various coated grains, bioclasts and intraclasts with numerous *Crescentiella* are commonly observed in many parts of Upper Jurassic, open marine, shallow-water platforms (above the storm wave base i.e., around 40–60 m depth) of the Tethyan Realm in the Central Europe (e.g., Leinfelder et al. 1996; Krajewski and Olszewska 2006; Matyszkiewicz et al. 2006, 2012; Schlagintweit and Gawlick 2008; Hoffmann et al. 2017; Pleš et al. 2017; Krajewski and Schlagintweit 2018; and references therein). On the northern Tethyan shelf area, such associations are common in a mid-ramp setting (e.g., Leinfelder et al. 1996; Senowbari-Daryan et al. 2008; Krajewski et al. 2016, 2018; Olchowcy et al. 2019). Both the oncoids and the aggregate coated

Fig. 7 Calcareous dinoflagellate cysts from the exotic clasts (photo: J. Kowal-Kasprzyk). **a** *Colomisphaera fibrata* (S5/13). **b** *Comittosphaera czestochowiensis* (S16/11). **c** *Colomisphaera lapidosa* (S29/12). **d** *Crustocadosina semiradiata semiradiata* (S29/11). **e** *Crustocadosina semiradiata semiradiata* (S30/1). **f** *Cadosina par-*

vula (S30/7). **g** *Colomisphaera carpathica* (S5/13). **h** *Colomisphaera minutissima* (S29/11). **i** *Colomisphaera pieniniensis* (S30/1). **j** *Stomiosphaera moluccana* (S13/5). **k** *Stomiosphaera moluccana* (S13/5) XPL. **l** *Carpistomiosphaera borzai* (S29/4)

grains indicate an environment close to the depth of the fair-weather wave base. The presence of type I and type II oncoids (e.g., Védérine et al. 2007) suggests a depositional environment of an open-sea, mid-inner ramp with moderate water energy.

The fine-grained biodetrital limestones (FT 3) facies is represented by fine-grained pelagic limestones. These deposits correspond very well to spiculite wackestones (standard microfacies—SMF 1; SMF's after Flügel 2004), microbioclastic peloidal calcisiltites representing the SMF 2 microfacies, and pelagic mudstones—wackestones representing the SMF 3 microfacies. The FT 3 was deposited in a deeper part of the basin in an outer-ramp setting (e.g., Flügel 2004). A part of *Saccocoma*-dominated sediments was primarily deposited from suspension on a sea floor of distinct relief and then became subsequently transported by turbidity currents; hence, they show graded bedding, typical

of calciturbidites (e.g., Matyszkiewicz 1996, 1997). The FT 2 facies forming clasts within the FT 3 sediments represents the gravity-flow material presumably redeposited, e.g., as debris flows from more shallow settings located close to the fair-weather wave base of moderate water energy.

Palynological analysis

The palynological analysis of 18 exotic limestones shows that they were deposited in various environments manifested by the presence or absence of organic-walled microfossils (palynomorphs). A factor responsible for this difference was likely the oxygen level in bottom waters. Well-preserved organic-walled dinoflagellate cysts from some exotics settled down under dysoxic bottom water conditions that enabled their preservation. The barren exotics (mainly pale-colored lithologies) represent deposits that presumably accumulated

Fig. 8 Organic-walled dinoflagellate cysts and foraminifera organic lining from exotic clasts (photo: P. Gedl). Scale bar refers to all photomicrographs. **a** *Ellipsoidictyum cinctum* (S19/20). **b** *Sentusidinium* sp. (S19/20). **c** *Epipllosphaera areolata* (S19/20). **d** *Epipllosphaera* sp. (S30/4). **e** *Chlamydophorella nyei* (S30/18). **f** *Cleistosphaeridium iaculigerum* (S30/4). **g** poorly preserved specimen of *Ctenidodinium* (S30/4). **h** *Sentusidinium rioultii* (S30/5). **i** *Mendicodinium*?

sp. B of Brenner (1988) (S19/20). **j** *Prolixosphaeridium mixtispinosum* (S19/20). **k** *Glossodinium dimorphum* (S19/20). **l** *Scrinioidinium dictyotum* (S19/20). **m** *Gonyaulacysta jurassica* (S30/5). **n** *Systematophora penicillata* (S19/20). **o** *Systematophora valensii* (S19/20). **p** *Systematophora areolata* (S19/20). **q** *Rhynchodiniopsis cladophora* (S19/20). **r** *Tubotuberella apatela* (S30/4). **s** *Endoscrinium luridum* (S30/5). **t** Foraminifera organic lining (S30/5)

Age Taxa	157.3		152.1	145.0	
	Oxfordian	Kimmeridgian		Tithonian	Berriasian
FORAMINIFERA					
<i>Spirillina tenuissima</i>	←				
<i>Ophth. pseudocarinatum</i>	←				
<i>Protopeneroplis striata</i>	←				
<i>Mohlerina basiliensis</i>	←				→
" <i>Globuligerina</i> "	←				→
<i>Bullopore tuberculata</i>	←				
<i>Ophthalmidium bolgradensis</i>					
<i>Eomarssonella paraconica</i>					
<i>Spirillina andreae</i>					
<i>Globuligerina oxfordiana</i>					
<i>Protomarssonella jurassica</i>					
<i>Rumanolina feifeli seiboldi</i>					
<i>Ophthalmidium strumosum</i>					
<i>Spirillina elongata</i>					
<i>Ammobaculites irregularis</i>					
" <i>Compactoger. stellapolaris</i> "					
<i>Pseudomar. ? dumortieri</i>					
<i>Rumanolina feifeli feifeli</i>					→
" <i>Cornuspira eichbergensis</i> "					
<i>Rumanolina feifeli elevata</i>					→
<i>Neotrocholina valdensis</i>					→
CALC. DINOFLAGELLATES					
<i>Colomisphaera fibrata</i>	←				
<i>Comm. czestochowiensis</i>					
<i>Colomisphaera lapidosa</i>					
<i>Cr. semiradiata semiradiata</i>					→
<i>Colomisphaera minutissima</i>					→
<i>Cadosina parvula</i>					
<i>Colomisphaera carapathica</i>					
<i>Colomisphaera pieniniensis</i>					
<i>Stomiosphaera moluccana</i>					→
<i>Carpistomiosphaera borzai</i>					
OTHER MICROFOSSILS					
<i>Terebella lapilloides</i>	←				
<i>Crescentiella morronensis</i>	←				→
<i>Saccocoma</i> sp.	←				
ORGANIC-WALLED DINOFLAGELLATE CYSTS					
<i>Gonyaulacysta jurassica</i>	←				
<i>Ellipsoidictyum cinctum</i>	←				
<i>Rhynchodiniopsis cladophora</i>	←				
<i>Aldorfia dictyota</i>	←				
<i>Leptodinium subtile</i>					
<i>Endoscrinium luridum</i>					
<i>Glossodinium dimorphum</i>					
<i>Systematophora areolata</i>					→
<i>Tubotuberella apatela</i>	←				→

Fig. 9 Stratigraphically significant calcareous microfossils—mainly foraminifers and calcareous dinoflagellate cysts—identified in the studied samples and their known age ranges (after Borza 1969; Řehánek and Cecca 1993; Řehánek and Heliasz 1993; Řeháková 2000; Olszewska et al. 2011, 2012; Olszewska 2014 and references therein), and stratigraphically important organic-walled dinoflagellate cysts and their age ranges (after Riding and Thomas 1988, 1992; Poulsen 1991, 1992, 1993, 1996)

under well-ventilated, oxygen-rich bottom water regime. The nature of the studied samples—isolated exotics—precludes the determination of disoxic/anoxic bottom water conditions as a regional event during the late Oxfordian–early Kimmeridgian or as a reflection of only local conditions.

The palynofacies composed chiefly of dinoflagellate cysts with only minor proportions of terrestrial phytoclasts as well as the taxonomic composition of the organic-walled dinoflagellate cyst assemblages suggest a fully marine sedimentary setting with limited land influences. The presence of organic foraminiferal linings additionally confirms the marine environment.

The comparison of the exotic assemblages with the Oxfordian–Kimmeridgian ones from epicontinental deposits of central and southern Poland reveals a similarity to the Oxfordian assemblages from the offshore facies of southern Poland (see Poulsen 1993). The Kimmeridgian assemblages from the shallow-water, near-shore environments of central Poland are different. They are rich in *Cribroperidinium* (and morphologically similar species like *Occisucysta* and *Tehamadinium*) and other characteristic forms like *Atlantodinium jurassicum* and *Amphorula dodekova* (see Poulsen 1996; Gedl and Ziaja 2004), which are rare or missing in the exotic material. The *Cribroperidinium* and similar morphotypes (e.g., *Trichodinium* and *Apteodinium*) occur also in the rather shallow-water Tithonian Vendryně Formation (see chapter 2.1), and they are associated with *Systematophora*/*Hystriosphera* and *Endoscrinium*/*Scriniodinium* morphotypes (Gedl and Szydło 2001). This may suggest that the motile stages of assemblages from exotics inhabited more offshore waters, similar to those which predominated in the epicontinental Oxfordian in southern Poland, rather than shallow, near-shore areas.

The offshore preferences of the motile stages of dinoflagellate cysts from the studied exotics can also be confirmed by a comparison with the Callovian–Oxfordian assemblages from the Grajcarek Unit (Magura Basin) and the Branisko Nappe of the Inner Carpathians. They yielded frequent specimens of *Systematophora* and proximochorate gonyaulacoids like *Sentusidinium* and *Epiplosphaera*, and lack *Cribroperidinium* morphotypes (see Gedl 2008).

It should be noted that three samples (S30/4, S30/5 and S30/18) with similar, taxonomically diversified dinoflagellate cyst assemblages represent the deepest facies FT 3. The sample S19/20 with a *Systematophora*-dominated

assemblage represents a shallower facies FT 1. However, there are too few data to draw further conclusions on palaeoenvironmental preferences.

Comparison of clasts and adjacent epicontinental deposits

The studied facies are similar to facies types known from the northern shelf area of the Western Tethys. Both the FT 1 and FT 2 facies show similarities to spongiolitic or sponge–microbial and biodetrital limestones facies with bioclasts, oncoids, intraclasts and *Crescentiella*, which are widely distributed over the northern shelf of the Western Tethys (e.g., southern Poland and southern Germany; e.g., Trammer 1989; Leinfelder et al. 1996; Matyszkiewicz 1997; Schmid et al. 2001; Matyszkiewicz et al. 2012 and references therein). The area closest to the sampling sites of in situ Oxfordian–lower Kimmeridgian facies occurrences is the southern part of the Kraków–Częstochowa Upland, nowadays some 15 km distant from these exposures (Fig. 1; e.g., Matyszkiewicz et al. 2012, 2016; Krajewski et al. 2018). It must be emphasized, however, that due to tectonic transport of the Carpathian nappes, this distance in the Late Jurassic was at least 60–70 km, according to the results of deep drillings (see Wdowiarz 1976; Ślaczka et al. 2006). This facies type dominates also in the Oxfordian strata described from the basement of the Carpathian Foredeep (e.g., Matyja 2009; Krajewski et al. 2011a; Morycowa and Moryc 2011). Moreover, deposits similar to the FT 1 facies are known from the Tithonian strata found in the basement of the Carpathian Foredeep (e.g., Matyja 2009; Krajewski et al. 2011a) and from the Tithonian organodetrital conglomerates embedded in the Cieszyn Limestone (e.g., Matyszkiewicz and Słomka 1994, 2004). In the southern part of the Kraków–Częstochowa Upland, the sponge–microbial facies occurs most widely in the upper Oxfordian (mainly *Bifurcatus* Zone) and/or in the lower Kimmeridgian deposits (mainly *Planula* Zone) (e.g., Matyszkiewicz et al. 2012; Krajewski et al. 2018). In this area, the rocks developed as medium- or thick-bedded limestones, together with massive, low-relief, segment or frame reefs (sensu Riding 2002), and represent vast reef complexes (e.g., Matyszkiewicz et al. 2006, 2012; Krajewski et al. 2018). Moreover, this facies is also dominating in clasts and blocks (up to several tens of centimeters in diameter) that occur in gravity-flow deposits (debris flows and olistoliths) developed in the southwestern part of the Kraków–Częstochowa Upland (e.g., Matyszkiewicz 1996; Woźniak et al. 2018; Woźniak and Bania 2019). Due to syndimentary tectonics, such debrites were deposited along the slopes of the ridges that followed the Kraków–Lubliniec Fault Zone—a vast tectonic structure that was active in the Mesozoic and separated the Małopolska and the Silesian terranes (e.g., Żelaźniewicz et al. 2011).

It is worth noting that similar sponge–microbial facies are observed also in the Tithonian exotic limestones known from the same study area (Kowal-Kasprzyk 2016, 2018). It may suggest that the sponge–microbial sedimentation had proceeded along the margins of the proto-Silesian basin at least until the end of the Jurassic. A similar feature is observed in the exotics from the Pieniny Klippen Belt, which represents the remnants of the Andrusov Ridge (Matyszkiewicz et al. 2004).

In case of the Kimmeridgian FT 3 facies, the closest analogs can be found in the basement of the Carpathian Foredeep, in Poland, and in Ukraine (Krajewski et al. 2011a,b; Olszewska et al. 2012). More rarely, such facies were observed in the extra-Carpathian central and southern Poland, i.e., in the northern Tethys shelf area (lower Kimmeridgian *Platynota* Zone) (e.g., Matyszkiewicz 1996; Krajewski et al. 2014; Woźniak and Bania 2019). In the Inner Carpathians, similar deposits, although containing filamentous–*Saccocoma* microfacies (wackestones–packstones), were described from the lower Kimmeridgian fine-grained pelagic facies of the Krížna Unit in the Tatra Mts. (e.g., Jach et al. 2012). Analogous, Kimmeridgian dark-gray limestone facies represented by spiculitic *Saccocoma* wackestones–mudstones with filaments and deposited as calciturbidites in the deep shelf and slope settings, was described from the basement of the Carpathian Foredeep of the western Ukraine, along the marginal ridge of the East European Platform (Krajewski et al. 2011b). Moreover, such rocks were encountered also in a few outcrops near the edges of tectonic ridges (margin of the Małopolska and Upper Silesian terranes) located in the southernmost part of the Kraków–Częstochowa Upland (Matyszkiewicz 1996, 1997) where they constitute the northern margin of the Carpathian Foredeep. These deposits are partly silicified, fine-grained pelagic packstones, wackestones and mudstones with peloids, small bioclasts, echinoderms, and loose, variously shaped remains of *Saccocoma* (Matyszkiewicz 1996), which show normal grading, rarely also cross-lamination. These rocks can be interpreted as calciturbidites laid down along the marginal parts of tectonic ridges and are genetically related to synsedimentary tectonic events. Their age was determined as lower Kimmeridgian (*Platynota* Zone). Matyszkiewicz (1996) described the outcrops of characteristic, 20-m-thick sequences, in which the lower Kimmeridgian reefs or biostromes (previously identified as the upper Oxfordian *Planula* Zone) are covered with calciturbidites with *Saccocoma*, identical with the FT 3 facies as well as by debris flows composed of blocks and clasts similar to the FT 2 facies, rarely even to the FT 1 one. These facies document the final stage of development of the middle Oxfordian–lower Kimmeridgian reef complexes in the Polish part of the Tethys shelf, i.e., a submersion of the platform followed by synsedimentary tectonic disturbances, which both

reflect the transregional geological events. A similar and contemporaneous sedimentary sequence was described from the Lothen area (Schwäbische Alb) in southern Germany (Keupp and Matyszkiewicz 1997; Matyszkiewicz 1997). Hence, it can be concluded that both the development and the depositional setting of the studied extraclasts resemble the Oxfordian–lower Kimmeridgian sedimentary succession in the adjacent southern part of the Kraków–Częstochowa Upland.

The Oxfordian deposits found in the klippe from both the Andrychów and the Kruhel areas as well as from the exotic block in Bachowice are also comparable—mainly due to the occurrence of epicontinental faunal assemblages (e.g., Olszewska and Wiczorek 2001; Olszewska et al. 2011)—to rocks from the northwestern Tethyan shelf. Similar faunal assemblages are also known from these parts of the Carpathian Foredeep, which were covered by the Carpathian overthrust and, thus, are known only from deep drillings (e.g., Olszewska in Wójcik et al. 2006).

Oxfordian–Kimmeridgian paleogeography

During the Oxfordian–Kimmeridgian, the study area was part of the southern margin of the northern Tethys shelf known as the Peri-Tethys, north of the Alpine Tethys (Fig. 10). The investigated exotic rocks indicate that during the Oxfordian, a broad carbonate platform was developed, similarly as on the adjacent Precarpathian Foredeep basement and the Kraków–Częstochowa Upland. Microbial–sponge and microbial–*Crescentiella* facies formed local, broad reef complexes on the platform. Particularly, intense reef development in the southern margin of the North Tethys shelf took place on uplifted areas associated with marginal parts of the broad tectonic zones separating the terranes (e.g., Upper Silesian and Małopolska terranes; Matyszkiewicz et al. 2006; Krajewski et al. 2018).

The Oxfordian–Kimmeridgian periodic disintegration of the carbonate platform into smaller paleogeographic elements took place during intervals of strong extensional tectonic events. They occurred in the Carpathian area as well as in both central and southern Poland (Kutek 1994; Golonka 2004; Golonka et al. 2008a; Krajewski et al. 2016; Matyszkiewicz et al. 2016). In southern Poland, middle Oxfordian–early Kimmeridgian (*Transversarium*–*Platynota* zones) synsedimentary tectonic activity is documented by intense development of gravity-flow deposits (olistoliths, debris flows, calciturbidites) and neptunian dykes along the marginal parts of broad tectonic zones (e.g., Matyszkiewicz 1996; Matyszkiewicz et al. 2006, 2012, 2016; Barski and Mieszkowski 2014; Woźniak et al. 2018; Woźniak and Bania 2019). Synsedimentary tectonics periodically active in the northern Tethyan shelf was related to the opening of the North Atlantic and Tethys oceans. It resulted in the Late

Fig. 10 **a** Paleogeography of the proto-Silesian (Severin–Moldavide) Basin and surrounding areas in the Oxfordian–Kimmeridgian (after: Golonka et al. 2006, 2008a, b; Krajewski et al. 2016, somewhat mod-

ified). **b** Position of southern margin of the North European Platform in the Late Jurassic (after: Olszewska and Wiczeorek 2001; Krajewski et al. 2016, simplified)

Jurassic stress-field reorganization, which also included the passive northern margin of the Tethys (e.g., Allenbach 2002; Nieto et al. 2012).

Based on the data from the study area and the adjacent regions, it can be assumed that uplifted and depressed zones in the Western Carpathians were paleogeographic elements as early as in the Oxfordian. Thus, in the late Oxfordian–Kimmeridgian, several paleogeographic elements, related to the origin of the discussed limestones, can be distinguished in the Polish part of southern margin of the North European Platform. The Silesian Ridge, situated between the proto-Silesian (later: Silesian) and the Magura basins, is usually interpreted as an elevated part of the North European Platform margin (e.g., Sikora 1976; Golonka et al. 2006). The Baška-Inwałd Ridge was located between the proto-Silesian and the Bachowice basins (e.g., Książkiewicz 1960, 1965; Olszewska and Wiczeorek 2001). According to Golonka et al. (2008a), this ridge originated in the Late Jurassic as a result of thermal uplift preceding the rifting, which involved the opening of the proto-Silesian Basin. The enigmatic Bachowice Basin possibly constituted the depressed zone of the North European Platform (Książkiewicz 1956a; Olszewska and Wiczeorek 2001; Golonka et al. 2008a), which is indicated by the differences in sedimentation noticeable since the Kimmeridgian (Olszewska et al. 2011).

Both the sedimentation and the facies architecture in the adjacent extra-Carpathian southern Poland may have

resulted also from the northeastern progradation of rifting from the southern areas towards the northern Tethyan shelf. This process might have generated the northeastern extension of parallel, northwest–southeast-trending swells and basins (e.g., Baška-Inwałd Ridge and Bachowice Basin) developed in the southern segment of the peri-Tethyan part of the platform. For example, Matyszkiewicz (1997) described the southern part of the Kraków–Częstochowa Upland as an elevation of the shelf margin based on the regional facies analysis and the low subsidence caused by magmatic intrusions ascending along the margin of the Małopolska terrane. Also, Krajewski et al. (2016) distinguished an elevated ridge (Kraków–Częstochowa Upland) located in the uplifted southern margin of the Małopolska terrane (Żelaźniewicz et al. 2011; Małopolska Ridge) and a deeper basin embracing the Miechów Depression and the Wieluń Upland.

Source areas of exotic limestones

The studied exotics originate from the Lower Cretaceous to Eocene flysch strata. In the majority of the studied localities, direct determination of paleotransport direction was impossible, but the general trends in distribution of predominant source areas supplying the Outer Carpathian basins and their changes in time are well known (Książkiewicz 1962; Unrug 1963; Ślaczka 1976; Leszczyński 1981). The Silesian Ridge is considered as the most important source area for

the proto-Silesian and, later on, for the Silesian Basin (e.g., Książkiewicz 1965; Eliáš 1970; Ślaczka et al. 2006). The Baška–Inwałd Ridge was the northern source area for the western part of the basin and was active mainly in the Early Cretaceous (e.g., Książkiewicz 1956a, 1965; Matyszkiewicz and Słomka 1994).

The studied localities within the Lower Cretaceous Hradiště Formation are situated close to the northern margin of the Silesian Unit and in the area of the Subsilesian Unit; hence, the exotics were most probably supplied to these basins from the Baška–Inwałd Ridge. During the Late Cretaceous and the Paleocene–Eocene, the detrital material was delivered to the Silesian Basin mainly from the southwest; thus, the exotics described from the Istebna and the Ciężkowice formations most probably originated from the erosion of the Silesian Ridge. The paleotransport indicators were directly analyzed in the field only in the Beskid Mały Mts. (sampling sites S29 and S30) where the exotics occur within the Upper Istebna Beds (Strzeboński et al. 2017). The results are consistent with the general trends described above. However, it must be taken into consideration that some exotics might have been recycled, i.e., reworked from older flysch deposits and resedimented in younger deposits (Książkiewicz 1956b; Matyszkiewicz and Słomka 1994; Cieszkowski et al. 2009; Strzeboński et al. 2017).

It should be noted that some differences are observed between the studied exotics derived from these two source areas. Among the exotics originating probably from the Baška–Inwałd Ridge, both the FT 1 and FT 2 facies prevail, whilst the FT 3 facies dominates in exotics coming presumably from the Silesian Ridge. The amount of study material as well as its dispersion and redeposition hinder some firm conclusions, but these data can suggest that in the sedimentary environment of the Baška–Inwałd Ridge rather the shallower facies were deposited in comparison with the Silesian Ridge area, which was situated further to the south.

During the Miocene tectonic movements, flysch deposits were detached from their original basement and thrust over Mesozoic rocks of the North European Platform. As a result, today mainly deposits filling the axial parts of the Outer Carpathians basins are observed (e.g., Książkiewicz 1931, 1977; Sikora 1976; Ślaczka et al. 2006; see also: Picha et al. 2006; Fig. 6). Due to the future uplift of the ridges followed by their erosion and redeposition of detrital material to the flysch series, the exotic rocks are the only known remnants of the pre-flysch Oxfordian–Kimmeridgian sedimentation in this area.

Conclusions

- The analysis of exotic clasts from southern Poland revealed new insights into the organic life and sedimentary conditions during the platform phase that preceded the development of the Outer Carpathian flysch basins.
- Micropaleontological and palynological data, and a comparison with epicontinental deposits, generally suggest an Oxfordian–Kimmeridgian age of studied exotic limestones. Also comparisons with other epicontinental deposits are confirming this stratigraphic interval.
- The exotics are defined by three facies types (FT 1–3). The sponge–microbial limestones (FT 1) can be interpreted as a mid-ramp facies, i.e., deposited mostly in a low-energy, nutrient-rich environment. Also, the oncoid–intraclast–*Crescentiella* limestones (FT 2) are related to a mid-ramp setting. The fine-grained biodetrital limestones (FT 3) were possibly deposited in deep shelf or toe-of-slope environments belonging to the outer-ramp setting. The land influence was not intense, and the pelagic/hemi-pelagic accumulation prevailed in the basin.
- The studied exotics share numerous facies characteristics with other synchronous carbonates widely distributed over the northern shelf area of the Western Tethys (e.g., southern Poland, southern Germany, Carpathian Foredeep). Coeval strata known from the southern part of the Magura Basin that stretched south of the Silesian Ridge and of the Penninic–Pieninic Ocean south of the Czorsztyn Ridge yielded different microfacies reflecting significant differences between the sedimentary settings of the study area and its southern extensions.
- The exotic limestone clasts originate from the period when destruction of the southern margin of the North European Platform has commenced. These limestones were possibly deposited in the areas of both the Silesian and the Baška–Inwałd ridges, which were a southward extension of parallel ridges and grabens that divided the northern Tethys shelf as a result of synsedimentary tectonic movements. The gradual evolution of this system finally resulted in the development of the proto-Silesian Basin.

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Appendix

List of the identified taxa.

- Calcareous-walled dinoflagellate cysts
Cadosina parvula Nagy, 1966
Carpistomiosphaera borzai (Nagy, 1966)
Colomisphaera carpathica (Borza, 1964)
Colomisphaera fibrata (Nagy, 1966)
Colomisphaera lapidosa (Vogler, 1941)
Colomisphaera minutissima sensu Nowak, 1968
Colomisphaera pieniniensis (Borza, 1969)
Committosphaera czestochowiensis Řehánek, 1993
Crustacadosina semiradiata semiradiata (Wanner, 1940)
Stomiosphaera moluccana Wanner, 1940
Foraminifers
Ammobaculites irregularis (Gümbel, 1862)
Bullopore tuberculata (Sollas, 1877)
“*Compactogerina stellapolaris*”
Cornuspira Schultze 1854
“*Cornuspira eichbergensis*”
Eomarssonella paraconica Levina, 1972
Globuligerina oxfordiana (Grigelis, 1958)
Lenticulina Lamarck, 1804
Mohlerina basiliensis (Mohler, 1938)
Neotrocholina valdensis Reichel, 1955
Nubecularia Defrance, 1825
Ophthalmidium bolgradensis (Ivanova et Dain, 1971)
Ophthalmidium pseudocarinatum (Dain, 1963)
Ophthalmidium strumosum (Gümbel, 1862)
Protomarssonella jurassica (Mityanina, 1957)
Protopeneroplis striata Weynschenk, 1950
Pseudomarssonella? dumortieri (Schwager, 1866)
Reophax de Montfort, 1808
Rumanolina feifeli elevata (Paalzow, 1932)
Rumanolina feifeli feifeli (Paalzow, 1932)
Rumanolina feifeli seiboldi (Lutze, 1960)
Spirillina andreae Bielecka, 1960
Spirillina elongata Bielecka et Pożaryski, 1954
Spirillina tenuissima Gümbel, 1862
Textularia Defrance, 1824
Other microfossils
Crescentiella morronensis (Crescenti, 1969)
Globochaete alpina Lombard, 1945
Saccocoma Agassiz, 1836
Terebella lapilloides Münster, 1833
Organic-walled dinoflagellate cysts
Acanthaulax venusta (Klement, 1960)
Aldorfia Stover et Evitt 1978
Chlamydophorella Cookson et Eisenack, 1958
Chlamydophorella nyei Cookson et Eisenack, 1958
Cleistosphaeridium iaculigerum (Klement, 1960)
Cribroperidinium nuciforme (Deflandre, 1939)
Ctenidodinium Deflandre, 1938
Dingodinium tuberosum (Gitmez, 1970)
Ellipsoidictyum cinctum Klement, 1960
Endoscrinium luridum (Deflandre, 1938)
Epiplosphaera Brenner, 1988
Epiplosphaera areolata Klement, 1960
Epiplosphaera bireticulata Klement, 1960
Epiplosphaera gochtii (Fensome, 1979)
Glossodinium dimorphum Ioannides et al. 1977
Gonyaulacysta Deflandre, 1964
Gonyaulacysta jurassica (Deflandre, 1938)
Leptodinium Klement, 1960
Leptodinium subtile Klement, 1960
Lithodinia Eisenack, 1935
Mendicodinium? sp. B of Brenner, 1988
Prolixosphaeridium mixtispinosum (Klement, 1960)
Rhynchodiniopsis Deflandre, 1935
Rhynchodiniopsis cladophora (Deflandre, 1938)
Scrinodinium dictyotum Cookson et Eisenack, 1960
Sentusidinium Sarjeant et Stover, 1978
Sentusidinium rioultii (Sarjeant, 1968)
Sentusidinium sparsibarbatum Erkmén et Sarjeant, 1980
Systematophora Klement, 1960
Systematophora areolata Klement, 1960
Systematophora penicillata (Ehrenberg, 1843)
Systematophora valensii (Sarjeant, 1960)
Systematophora varispinosa Brenner, 1988
Systematophora vestita Deflandre, 1938
Tubotuberella Vozzhennikova, 1967
Tubotuberella apatela (Cookson et Eisenack, 1960)
Tubotuberella uncinata (Brideaux, 1977)
Tubotuberella ?whatleyi (Sarjeant, 1972)
Valensiella Eisenack, 1963

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