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BIOSTRATIGRAPHY AND DEPOSITIONAL ANATOMY OF A LARGE OLISTOSTROME IN THE EOCENE HIEROGLYPHIC FORMATION OF THE SILESIAN NAPPE, POLISH OUTER CARPATHIANS

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Abstract: The study focuses on a large olistostrome unit (~200 m thick and 4 km in strike-parallel extent) embedded in the Mid-Eocene shaly Hieroglyphic Formation of the Silesian Nappe, exposed in the Rożnów Lake area. Foraminifer biostratigraphy and petrographic comparisons are used to identify the provenance of olistoliths. The olistostrome is tripartite with respect of its olistolith composition. The lower part of the olistostrome abounds in olistoliths of sandstones derived from the Early Eocene turbiditic Ciężkowice Formation, whereas the middle part is dominated by olistoliths of Early Eocene bathyal mudshales. The upper part contains olistoliths of Middle Eocene turbiditic "banded sandstones", known from the Hieroglyphic Formation and deposited in the bathyal zone above the CCD. The bathyal provenance of the olistostrome contrasts with the abyssal origin of the hosting green shales.

The olistostrome unit is inferred to be composite, emplaced in the earliest Bartonian or at the Lutetian/Bartonian transition by a series of at least three large debris flows that closely followed one another. Biostratigraphical data and slump-fold vergence suggest resedimentation from the bathyal northern slope of the Silesian Cordillera that bounded the abyssal Silesian Basin to the south. Northward movement of the thrust-formed cordillera must have warped up the base-of-slope deposits of the Ciężkowice Formation, causing their gravitational collapse. This event destabilized the former lower-slope muddy deposits, resulting in a second phase of resedimentation by retrogressive slumping, which led to the collapse of mid-slope sandy turbidites. The slope failures involved contemporaneous Mid-Eocene sediment with an admixture of foraminifers derived from the upper slope or shelf margin and with exotic bedrock debris shed from the eroded cordillera crest. The catastrophic multi-phase emplacement of the olistostrome marked the last major thrusting pulse of the second (Late Cretaceous–Late Eocene) stage of tectonic evolution of the Outer Carpathian accretionary prism.

Key words: olistostrome, olistoliths, foraminifers, flysch, Eocene, Outer Carpathians.

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INTRODUCTION

Olistostromes varying in provenance and dimensions have been reported from all the main tectono-stratigraphic units of the Outer Carpathian flysch (e.g., Książkiewicz, 1958; Ślączka, 1964; Szymakowska, 1966, 1967, 1981; Oszczypko and Ślączka, 1987; Kotlarczyk, 1988; Polak, 1999; Rajchel, 2004; Cieszkowski and Golonka, 2006; Olszak, 2006; Cieszkowski *et al.*, 2007, 2008a, b, 2009a, 2012a; Jankowski, 2007, 2008; and references therein). The olistostromes are embedded in turbiditic successions and range from isolated thick solitary beds to multiple-bed complexes several hundred metres thick. The origin of olistostromes in active-margin tectonic settings is generally related to the topographic relief of the orogen thrust front and accretionary-prism ridges, known as cordilleras (e.g., Lucente and Pini, 2008; Oszczypko and Ślączka, 1987; Jankowski, 2007, 2008; Cieszkowski *et al.*, 2009a; and references therein). Olistostrome deposits also may be associated with high-relief fault blocks in passive-margin settings (e.g., Naylor, 1981; Callot *et al.*, 2008) and the strongly uplifted shoulders of rift basins (e.g., Wendorff, 2005a, b, 2011; Bailey *et al.*, 1989), as reported from the Carpathians and the forebulge margin of the European Platform (Waśkowska *et al.*, 2009; Cieszkowski *et al.*, 2012b; and references therein). As regards the provenance of material, the olistostrome varieties in the Outer Carpathians include both allolistostromes and endolistostromes (*sensu* Raymond, 1978). The former consist of exotic debris derived from bedrock that was uplifted and subjected to mass wasting, whereas the latter contain solely resedimented intraformational material. Olistostromes of mixed provenance have also been recognized.

Detailed regional studies of the Carpathian olistostromes (e.g., Olszak, 2006; Jankowski, 2007, 2008; Cieszkowski *et al.*, 2009a, b, 2012b) have been paralleled by comparative research in the Alps, Apennines and Sicilian Maghrebides (e.g., Cieszkowski *et al.*, 1994, 1995, 2006a, 2009a, 2010a; Pescatore *et al.*, 2010; Ślączka *et al.*, 2011, 2012). The results were summarized by Cieszkowski *et al.* (2009a), who also discussed the relationship between the origin of olistostromes and the main tectonic development stages of the Northern Carpathians.

The present study focuses on one of the largest olistostrome units in the Northern Carpathians, which is embedded in the Eocene Hieroglyphic Formation of the Silesian Nappe and is well exposed in the shoreline cliffs of Rożnów Lake, north of Nowy Sącz. The olistostrome was discovered and first described by Cieszkowski (1992, 1999), with further details reported by Cieszkowski *et al.* (2009b, 2010b, 2012b) and Cieszkowski and Waśkowska (2013a, b). The present paper addresses the important issues of the olistostrome unit's biostratigraphy and compound depositional anatomy, thereby shedding a new light on the origin and emplacement time of this large olistostrome.

GEOLOGICAL SETTING

The Carpathians are one of the major branches of the European Alpides. The Polish Carpathians are the central segment of the Northern Carpathian mountain chain, passing south-eastwards into the Eastern Slovak and Ukrainian Carpathians and south-westwards into the Western Slovak and Czech Carpathians. The Northern Carpathians are subdivided into inner and outer domains (Maheľ, 1974; Książkiewicz, 1977; Cieszkowski *et al.*, 1985; Ślączka and Kaminski, 1998; Golonka *et al.*, 2005, 2006; and references therein). The Outer Carpathian domain of the accretionary prism consisted of several deep-water basins separated by shallowly submerged or partly emerged cordilleran ridges (Książkiewicz, 1962, 1977; Ślączka and Kaminski, 1998; Golonka *et al.*, 2005, 2006, 2013; and references therein). One of these deep synclinal basins was the Silesian Basin, separated by Silesian Cordillera from the adjacent Magura Basin to the south. The basin evolved in Jurassic to Miocene time and was filled with turbiditic deposits. After the Miocene, northward tectonic thrusting had folded the Silesian Basin and uprooted it from the bedrock, forming the Silesian Nappe (Książkiewicz, 1962, 1977; Golonka and Waśkowska, 2007; Golonka *et al.*, 2013).

The Silesian Nappe occurs in the central segment of the Outer Carpathians (Fig. 1A; Książkiewicz, 1965, 1977; Koszarski *et al.*, 1974; Cieszkowski *et al.*, 1985; and references therein), thinning out southwards beneath the younger Magura Nappe and the Fore-Magura nappe complex (Fore-Magura Zone *sensu* Książkiewicz, 1965; see also Książkiewicz, 1977; Ślączka and Golonka, 2006). The Silesian Nappe was thrust northwards over the Subsilesian Nappe. They both overlie the older Skole Nappe in the eastern sector of the Polish Carpathians and cover directly Miocene foredeep molasse in the western sector.

The Silesian Nappe comprises a siliciclastic sedimentary succession of Late Jurassic to Early Miocene age, known as the Silesian Series, with a cumulative stratigraphic thickness estimated at 5–7 km or possibly more. These deposits represent the original Silesian Basin. The tectonic structure of the Silesian Nappe in the western sector involves shallow and gentle open folds, whereas long and narrow, steeply imbricated folds predominate in the eastern sector.

The study area north of Nowy Sącz is located in the middle part of the Silesian Nappe (Fig. 1A), where extensive outcrops are afforded by shoreline cliffs of the artificial Rożnów Lake in the Dunajec River valley (Fig. 1B). Good quality outcrops are due to seasonal lake-level changes of several metres with the related abrasion of coastal escarpments. The Silesian Nappe exposed in this area is a turbiditic succession of Late Cretaceous to Oligocene age (Burtan and Skoczylas-Ciszewska, 1963; Cieszkowski, 1992). These rocks form the southern limb of the so-called Rożnów Anticline (Sokołowski, 1935; Książkiewicz, 1977; Cieszkowski, 1992; Cieszkowski and Waśkowska, 2010; Cieszkowski *et al.*, 2010c), with the beds dipping southwards at 10–45°. The lake's eastern shore to the south of Bartkowa (Fig. 1B) shows a complete Palaeogene section of the Silesian Nappe. It consists of the Ciężkowice Sandstone Formation with two or three horizons of variegated shales, overlain by the Hieroglyphic Formation whose main upper part consists of green shales (Fig. 1B). These deposits are covered by the Globigerina Marl Formation and the Menilite and Krosno formations (Figs 1B, 2A).

The large olistostrome in the focus of the present study is ~200 m thick and embedded in the Hieroglyphic Formation (Fig. 2B), which otherwise consists of thinly bedded sandy-shaly to shaly flysch. The outcrop section studied is in the villages of Lipie and Gródek on the south-eastern shore of Rożnów Lake (Fig. 1B).

METHODS

Detailed field study was carried out to collect data on the lithostratigraphic position, petrographic composition, depositional architecture and stratigraphic age of the olistostrome. In addition to macroscopic observations, samples of the olistostrome matrix, shaly olistoliths and adjacent flysch deposits were analysed in thin sections using a Nikon LV 100POL microscope. Descriptive terms such as mudshale and clayshale are after Folk (1974).

To determine the olistostrome age, the micropalaeontological analysis of sediment samples focused on foraminifer assemblages. Fifteen mudstone samples were collected from the olistostrome and stratigraphically adjacent deposits (Table 1). The investigated material was prepared by standard micropalaeontological methodology, including

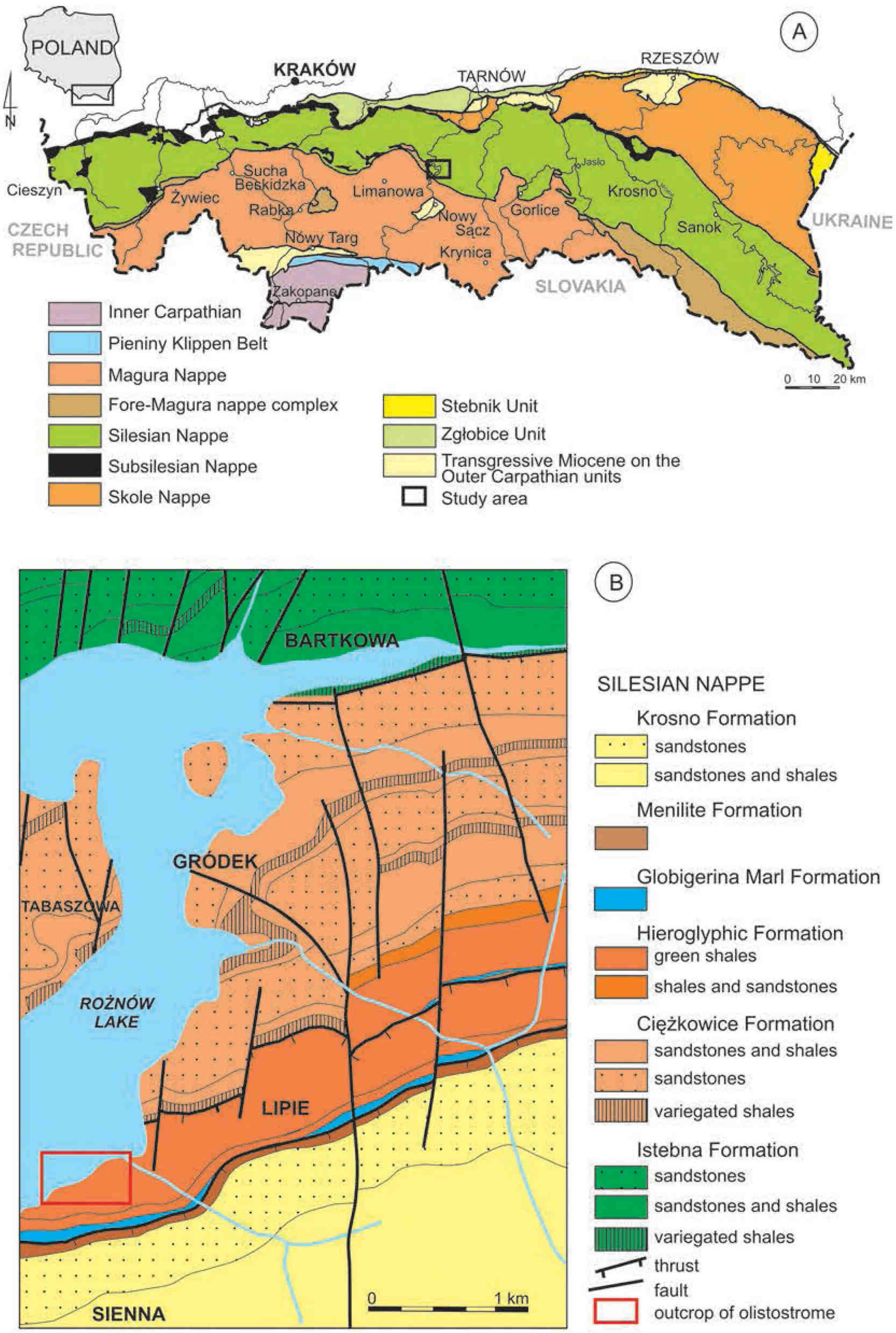


Fig. 1. Geological setting of study area. **A.** Simplified geological map of the Polish Carpathians (modified from Żytko *et al.*, 1989) with location of the study area. **B.** Geological map of the Rożnów Lake area (modified from Cieszkowski, 1992) with location of the studied olistostrome outcrop.

maceration in Glauber salt mixed with water and washing on 0.068–3 mm sieves. Foraminifer tests were separated from the residuum and taxonomically identified (Table 1) using a Nikon MSZ 1500 stereomicroscope equipped with Digital SIGH DS-Fi1 camera. The foraminifer assemblages were further subject to biostratigraphical analysis. The studied samples are housed at AGH in the first author's collection.

Table 1

Taxonomical distribution of foraminifers in the analysed samples from the olistostrome and "background" muddy turbidites

	Background turbidites				Olistostrome							
	Below olistostrome		Above olistostrome		Olistoliths				Matrix			
Sample no.	HF-1	HF-2	HF-3	HF-4	CG-5	CG-6	CG-7	CG-8	CP-11	MX-13	MX-14	MX-15
Ammomarginulina aubertae Gradstein et Kaminski					X ?							
Ammobaculites sp.					I						I	
Ammodiscus cretaceus (Reuss)		I	I	I		X	II	III		I		
Ammodiscus latus Grzybowski				I	II							
Ammodiscus tenuissimus Grzybowski			I			I	I	I				
Ammodiscus peruvianus Berry	II	I	X	II	III	X	III	I	I		I	I
Ammodiscus sp.	II		II		I	V	I			I		
Annectina grzybowskii Jurkiewicz			I?			II	I	I				
Annectina sp.			X		I							
Ammolagena clavata Jones et Parker					I	I						
Ammosphaeroidina pseudopauciloculata (Mjatliuk)	III			V	V		I					
Ammosphaeroidinina/Cystammina sp.						I						
Bathysiphon sp./*Nothia* div.sp. (fragments)	V	X	XV	XV	X	X	V	X	V	III	III	V
Bulbobaculites sp.					I							
Conglophragmium irregulais (White)				I	I	XV	III					
Cribrostomoides sp.			III	II			I	II				I
Cystammina/Praecystammina sp.		III	X	III	V					XV	III	V
Dolgenia sp.		I	II	I	II	I	I			I		I
Eratidus gerochi Kaminski et Gradstein				I	I ?							
Eggerelloides sp.				I		I?						
Glomospira charoides (Jones et Parker)		II	X	II	III	XI	V	X	I	I		I
Glomospira glomerata (Grzybowski)		I	I			V	I	I				
Glomospira gordialis (Jones et Parker)	II	I	V	II	I	II	III	V			I	
Glomospira diffundens Cushman et Renz						II		I				
Glomospira irregularis (Grzybowski)			I		I	II						
Glomospira serpens (Grzybowski)		I	I	I	I		I					
Glomospira sp.			I					I				
Gyroidinoides sp.						I						
Haplophragmoides kirki Wickenden		I	I				II					I
Haplophragmoides walteri (Grzybowski)	I	I	V	III	V	XV	III	V		I		
Haplophragmoides parvulus Blaicher	III	II		III	V							
Haplophragmoides cf. *parvulus* Blaicher					X							
Haplophragmoides porrectus Maslakova			I	I				I				
Haplophragmoides sp.		I	I			I					I	
Hyperammina sp.				I	I		I					I
Karrerulina coniformis (Grzybowski)		I	X	I	I	XX	III	V	II	II	I	I
Karrerulina conversa (Grzybowski)			I	II		XV	I	II				
Paratrochamminoides olszewskii (Grzybowski)						III						
Paratrochamminoides div. sp.	XV	V	XV	X	XV	X	X	XV	III	I	II	I
Placentammina placenta (Grzybowski)		I		I		I	II					
Popovia beckmanni (Kaminski et Geroch)	III	I	I			II	I					
Psammosiphonella (mainly *P. cylindrica* Glaessner (fragments))	XI	X	X	X	XV	XI	X	XV	III	I	II	II
Psammosphaera irregularis (Grzybowski)					II							
Pseudonodosinella elongata (Grzybowski)		I	I	I			I	II				
Pseudonodosinella nodulosa Brady		I	II	I		V	II	III				
Praesphaerammina gerochi Hanzlikova						I	I	II				

Table 1 continued

	Background turbidites				Olistostrome							
	Below olistostrome		Above olistostrome		Olistoliths				Matrix			
Sample no.	HF-1	HF-2	HF-3	HF-4	CG-5	CG-6	CG-7	CG-8	CP-11	MX-13	MX-14	MX-15
Praesphaerammina subgaleata Vasicek				I	X							
Recurvoides div. sp., *Thalmannammina subturbinata* (Grzybowski), *Recurvoidella lamella* (Grzybowski)	XV	X	XV	X	XI	XX	X	V	I	III	II	III
Reophax pilulifer Brady				II	I							
Reophax duplex Grzybowski		I	I	I			I					
Reophax sp.						I		I				
Reophax – single chambers	II	III		II	I	III		II			I	
Reticulophragmium amplectens (Grzybowski)	XV	X	I	V	X							
Saccammina grzybowskii (Schubert)					I							
Saccammina sp.					I					I		
Spiroplectammina navarroana Cushman			X			XV			I	X	II	V
Spiroplectammina spectabilis (Grzybowski)			V	I		XI	V	V			I	
Subreophax pseudoscalaris (Samuel)		I	I			III	I	II				
Trochammina globigeriniformis (Jones et Parker)			III	I						I		
Trochammina sp.		I	I		I	XI						I
Trochamminoides elegans (Grzybowski)						I	I	I				
Trochamminoides subcorantus (Grzybowski)		I		II		III		I				
Trochamminoides grzybowskii Kaminski et Geroch		II		II		V		II			I	
Trochamminoides proteus (Karrer)					V	V		I				
Trochamminoides variolarius (Grzybowski)				I	I	I	II	I			I	
Fish tooth						I						

The classes of specimen number frequency per sample are: (I) 1–5, (II) 6–10, (III) 11–20, (V) 21–50, (X) 51–100, (XV) 101–200, (XI) 201–500 and (XX) ≥501. Samples CP-9, CP-10 and CP-12 from beige-colour hard marlstone olistoliths and sample MX-11 from olistostrome matrix were barren

DESCRIPTION AND INTERPRETATION OF DEPOSITS

Background turbidites

The olistostrome-hosting Hieroglyphic Formation consists of thinly bedded sandy-shaly to shaly turbidites. The sandstones are thin- or occasionally medium-bedded, grey and greyish-green, fine-grained and well sorted, showing mainly planar parallel stratification and subordinate ripple cross-lamination. Bouma-type turbidites T*bcd* and T*cd* predominate, accompanied by rare tubidites T*abcd*. The basal surfaces of sandstone beds commonly show small mechanical or biogenic sole marks (referred to as hieroglyphs in Polish, and hence the formation's name). The sandstones are composed mainly of quartz grains with an admixture of detrital feldspar, muscovite and glauconite as well as coalified plant detritus. Cement is siliceous or siliceous-clayey. The sandstones are intercalated with greyish-green or occasionally brownish shales, generally non-calcareous. The shales predominate in the outcrop section studied, as sandstone beds thin upwards and gradually disappear in the turbiditic succession.

The upper part of the Hieroglyphic Formation consists of shales passing upwards into marly shales near the top. In the regional literature, the sandy-shaly lower part of the succession has been traditionally referred to as the Hieroglyphic Beds and the main shaly upper part as the Green Shales (e.g., Burtan and Skoczylas-Ciszewska, 1964; Koszarski *et al.*, 1964; Kuciński, 1965; Koszarski, 1966; Koszarski and Żytko, 1966; Cieszkowski *et al.*, 1991; Cieszkowski, 1992; Leszczyński and Radomski, 1994). The total thickness of the Hieroglyphic Formation in the study area (Fig. 1B) is estimated at ~350 m (Cieszkowski, 1992).

Olistostrome and its composition

The olistostrome occurs in the shaly middle part of the Hieroglyphic Formation (Fig. 1B) and has a thickness of 170–210 m. Its strike-parallel lateral extent is estimated to be at least 4 km and possibly up to 7 km. The olistostrome is a chaotic sandy-gravelly deposit rich in large intraformational and exotic clasts of varying size, including huge olistoliths up to a few hundred metres in length (Figs 2–5). The matrix is an unsorted mixture of siliciclastic mud, sand and fine-grained gravel, including clasts of sedimentary rocks (mainly mudstones, subordinate marls and minor limestones; Figs 3B, C, 5B, C). The sand is dominated by quartz, with subordinate feldspar, muscovite and plant detritus, whereas the calcareous component is limited mainly to foraminifer tests.

Olistoliths represent a range of sedimentary and crystalline rocks, but mainly fragments of mudstones and sandstones (Figs 3–5). The largest olistoliths are blocks 100–300 m in length and up to 15–20 m in thickness, representing

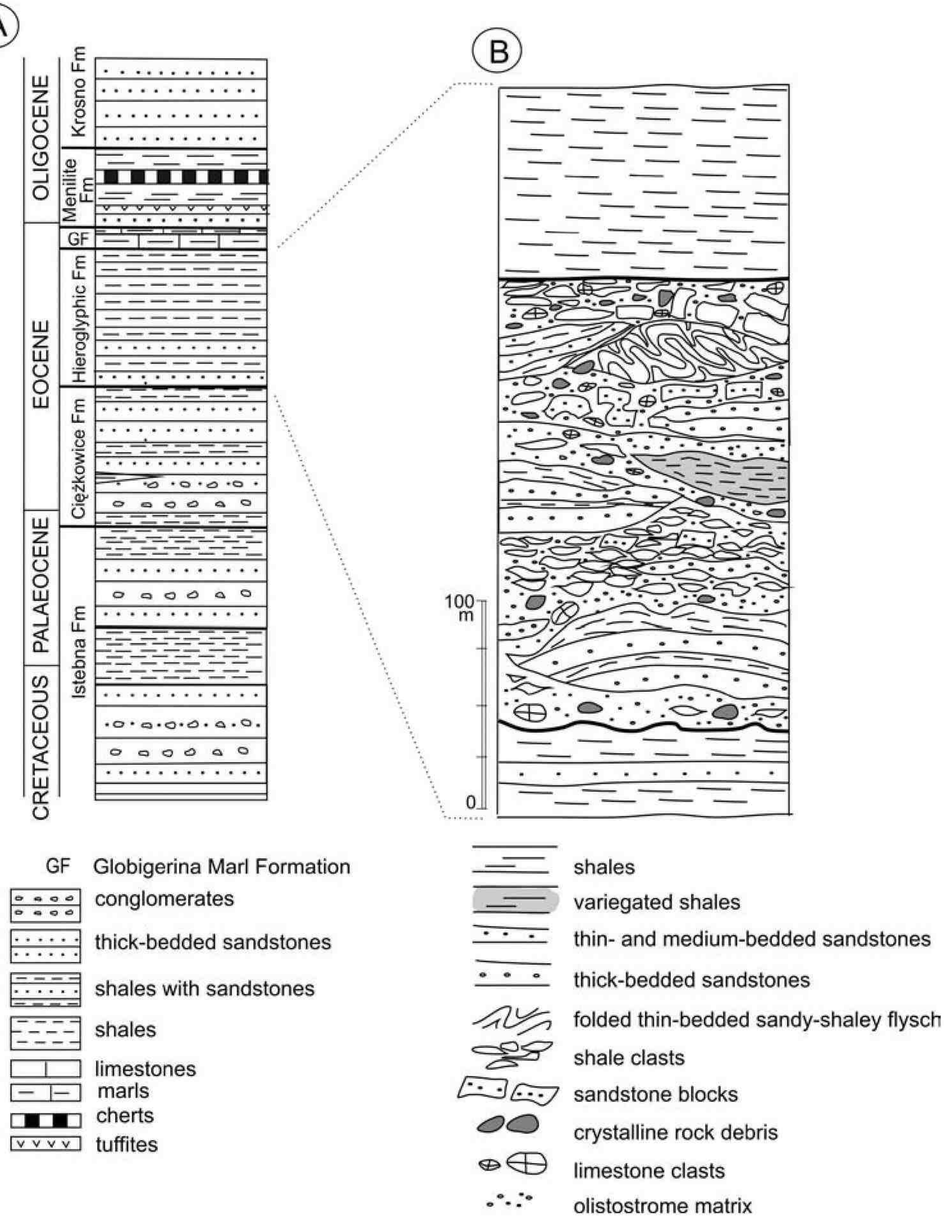


Fig. 2. Position of the olistostrome. **A.** Litostratigraphic log of the Silesian Nappe in Rożnów Lake area (Fig. 1B). **B.** The facies context of the olistostrome embedded in the Hieroglyphic Formation.

packages of internally non-deformed sandy-shaly or shaly flysch similar to the deposits of the Hieroglyphic Formation (Figs 3B, 4). Some of the blocks of thinly bedded flysch show relic slump folds (Fig. 5A, E), whereas some others contain marly shale interlayers and/or interbeds of light-grey, fine- to coarse-grained, parallel-stratified quartzose sandstones 0.5–1.2 m thick.

Blocks of thick-bedded sandstones closely resemble deposits of the Ciężkowice Formation (Fig. 5H). These sandstones are medium- to coarse-grained, partly conglomeratic, and light-grey, yellowish or bluish-grey in colour. Some other sandstones (Fig. 3F) are composed of quartz and carbonate grains with an admixture of muscovite. Calcareous grains are bioclasts comprising foraminifers, remnants of bryozoans, algae, echinoids and molluscs. Shaly olistoliths consist of light-to dark-grey, beige, greenish-grey or green mudstones, variegated mudstones/claystones, and beige marly mudstones (Figs 3A, D–G, 4). Some of them resemble the green shales of the Hieroglyphic Formation. The largest olistolith, composed of variegated shale, was mapped over a distance of more than 300 m (Cieszkowski, 1992). Also present are olistoliths of variegated marls containing Maastrichtian foraminifer assemblages (Cieszkowski, 1992), similar to those described by Ślączka and Gasiński (1985) from a marly olistolith in the Istebna Formation near Rożnów. Occurring sporadically are clasts of Upper Jurassic Štramberk-type limestones as well as armoured balls formed of rolled-up soft limestone layers (Fig. 5I), the largest exceeding 40 cm in diameter. Crystalline rock debris ranges in size from pebbles to boulders up to 50 cm in diameter, representing gneisses, granite-gneisses, metamorphic schists (mainly quartzose-micaceous) and vein quartz (Fig. 5G).

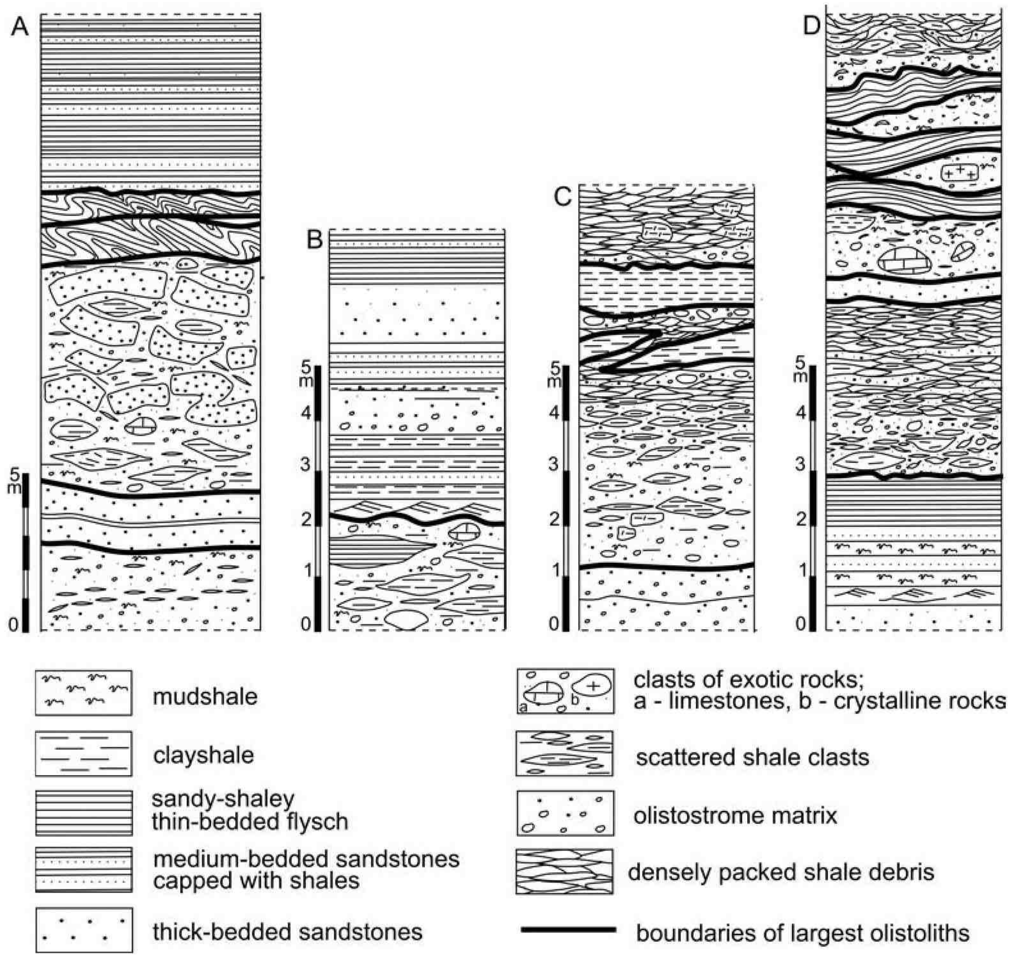


Fig. 3. Example lithological logs from the olistostrome in the Hieroglyphic Formation (slightly modified from Cieszkowski *et al.*, 2012). **A.** The upper part of the olistostrome, containing olistoliths of turbiditic sandstones and sandy-shaly flysch. **B, C.** The middle part of the olistostrome, rich in shaly olistoliths. **D.** The upper part of the olistostrome, bearing olistoliths of sandy-shaly flysch.

Olistostrome architecture

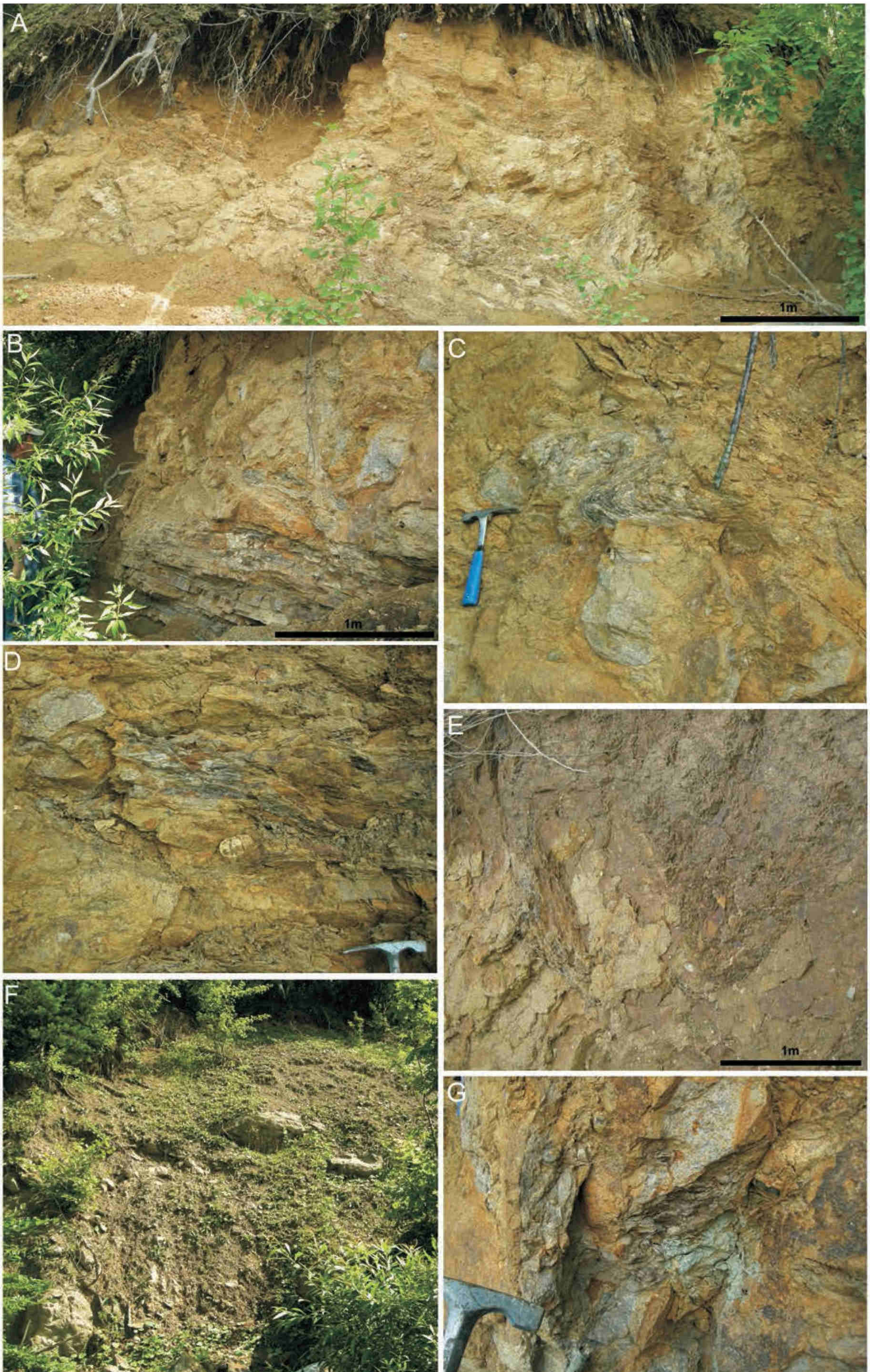
The olistostrome has a chaotic (massive) internal structure and "blocks-in-matrix" texture, with randomly scattered olistoliths floating in unsorted coarse-grained matrix (Fig. 4). However, the largest olistoliths occur as rafted slabs roughly parallel to the bedding surfaces, and also most of the smaller ones tend to be aligned parallel to the bedding (Fig. 3). Furthermore, the olistostrome shows a distinct compositional tripartition in its vertical stratigraphic profile. Its lower part is relatively rich in large sandstone olistoliths similar to the sandstones of the underlying Ciężkowice Formation (Figs 1B, 2). The middle part abounds in small and large shaly olistoliths (Fig. 3) resembling the green shales of the Hieroglyphic Formation. The upper part in turn is dominated by olistoliths of thinly bedded flysch, similar to the sandy-shaly turbidites of the Hieroglyphic Formation, although often folded and occasionally containing medium to thick sandstone interbeds.

The subordinate more exotic olistoliths – such as the debris of Maastrichtian marls and Upper Jurassic limestones or crystalline-rock gravel – are significantly smaller in size and seem to be scattered in the olistostrome without any obvious stratigraphic trend.

Depositional processes

The thinly bedded background turbidites of the Hieroglyphic Formation are the distal deposits of low-density (turbidites T*bcd* and T*cd*) and sporadic high-density turbidity currents (turbidites T*abcd*) *sensu* Lowe (1982). The layered shaly upper part of the formation represents hemipelagic sedimentation combined with the vertical stacking of mud turbidites (*sensu* Stow and Shanmugam, 1980), deposited by extremely dilute turbidity currents. Taken together, these turbiditic facies indicate a sand-starved "distal" environment of flysch deposition.

The thick olistostrome unit stands out as an isolated breccia "megabed" that differs strikingly from the background deposits and suggests a rare catastrophic event. The mud-bearing matrix and chaotic structure of the olistostrome indicate the emplacement mechanism of a non-turbulent cohesive debris flow (Lowe, 1982), with the alignment of olistoliths reflecting laminar shear. The folds exhibited by the flysch olistoliths (Figs 4A, C, 5A, E) are narrow, with amplitudes of 2–3 m and a northern vergence, indicating hydroplastic synsedimentary deformation and apparently representing disrupted recumbent slump folds. The tripartite compositional architecture of the olistostrome sug-


A
1m
B
1m
C
D
E
1m
F
1m
G

gests at least three consecutive debris flows, which closely followed one another, yet derived from somewhat different source materials. The genetic issue of sediment provenance and pattern of emplacement is discussed further in a subsequent section.

BIOSTRATIGRAPHY

Foraminifers in background turbidites

For comparative purposes, samples were taken from the muddy turbidites directly below the olistostrome (samples HF-1 and HF-2 in Table 1) and directly above it (samples HF-3 and HF-4 in Table 1). These deposits are non-calcareous, light-grey mudshales interlayered with greenish-grey clayshales, slightly deformed and representing the Green Shales of the Hieroglyphic Formation.

The foraminifer tests there are well preserved (Fig. 6), although their assemblages are represented only by agglutinated forms, dominated by long-ranging cosmopolitan taxa belonging to the category of deep-water agglutinated foraminifers (DWAF). Predominant are specimens of the genera *Bathysiphon*, *Rhabdammina*, Psammosiphonella (fragments of tubular chambers), *Paratrochamminoides* and *Trochamminoides*, accompanied by *Recurvoides* and *Thalmannammina* (Table 1). *Reticulophragmium amplectens* (Grzybowski) (Fig. 6I–K) and *Haplophragmoides parvulus* Blaicher (Fig. 6M) occur as a common component in all of the assemblages analysed. Samples from above the olistostrome contain also *Ammodiscus latus* Grzybowski Fig. 6 A–C), *Eratidus gerochi* Kaminski et Gradstein and *Praesphaerammina subgaleata* Vašíček (Fig. 6O, P).

In the Outer Carpathian flysch, *Reticulophragmium amplectens* (Grzybowski) appears at the end of the Early Eocene (Jurkiewicz, 1967; Geroch and Nowak, 1984; Olszewska, 1997) and its acme is dated to the Lutetian (Jurkiewicz, 1967; Morgiel and Szymakowska, 1978; Olszewska *et al.*, 1996, Chodyń and Waśkowska-Oliwa, 2006). According to the integrated biostratigraphical zonation for Carpathians (Olszewska, 1997), this stratigraphic interval is defined as the Reticulophragmium amplectens Zone. It is delimited by the last occurrence of *Saccamminoides carpathicus* Geroch and the first occurrence of *Ammodiscus latus* Grzybowski. *Haplophragmoides parvulus* Blaicher is known from the Bartonian (Olszewska *et al.*, 1996; Olszewska, 1997; Golonka and Waśkowska, 2011a; Golonka and Waśkowska, 2012).

The taxonomical composition of the foraminifer assemblages from below the olistostrome (Table 1) corresponds to the Reticulophragmium amplectens Zone, although the assemblages show relatively low taxonomic diversity. The Middle Eocene in the Outer Carpathians generally contains much more diversified assemblages (e.g., Geroch and Gradziński, 1955; Geroch, 1960; Liszkowa, 1956; Geroch *et al.*, 1967; Jurkiewicz, 1967; Cieszkowski *et al.*, 2011; and references therein), but also with *Reticulophragmium amplectens* (Grzybowski) occurring in association with *Haplophragmoides parvulus* Blaicher.

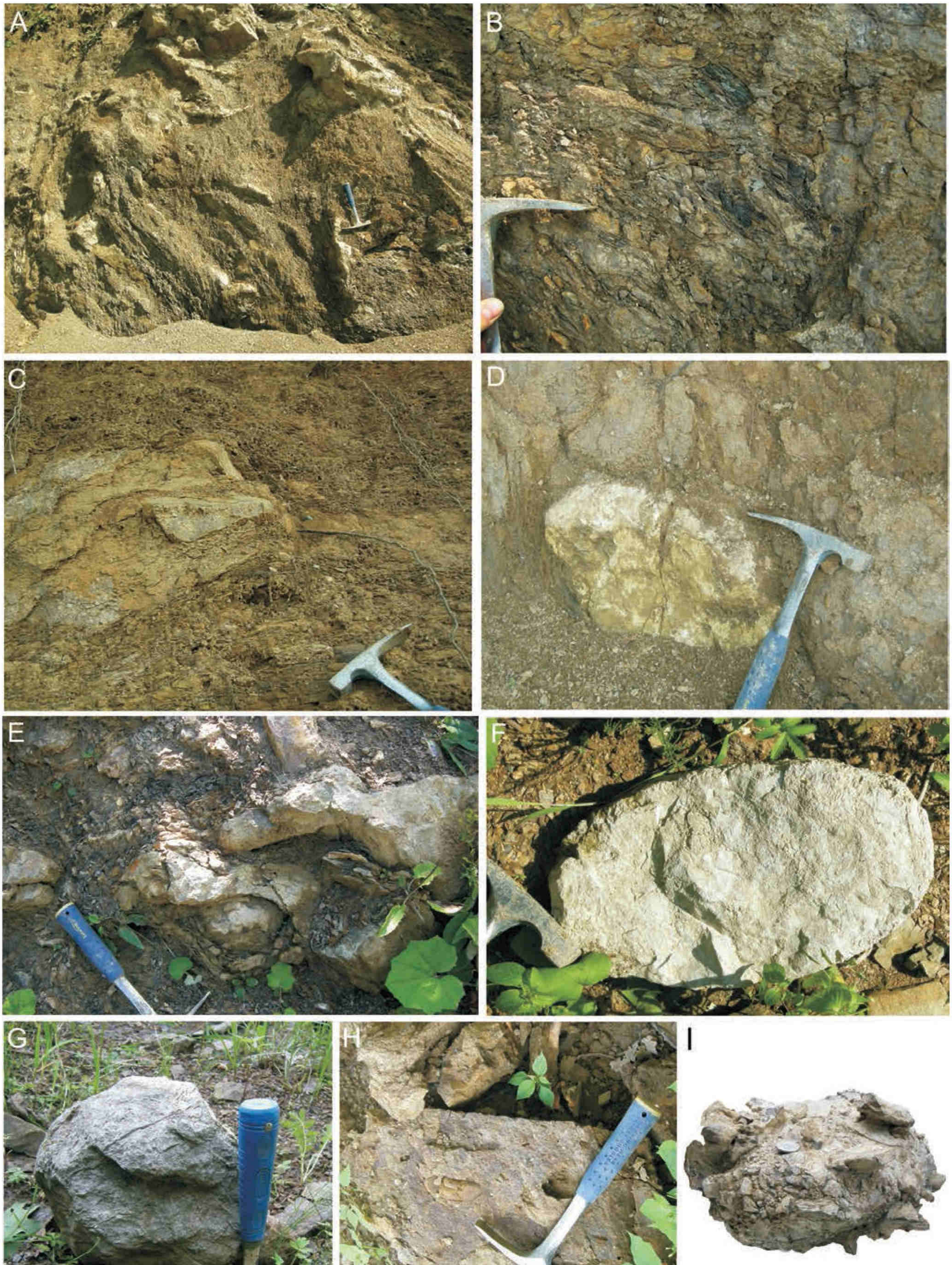
Foraminifer assemblages from above the olistostrome (Table 1) indicate the Ammodiscus latus Zone. The species *Ammodiscus latus* Grzybowski, which is characteristic for these assemblages, occurred in the Outer Carpathians in the Bartonian (Jurkiewicz, 1967; Olszewska *et al.*, 1996) and co-occurred with frequent *Reticulophragmium amplectens* (Grzybowski) in the lower part of the Ammodiscus latus Zone (Geroch, 1960; Jurkiewicz, 1967; Geroch and Nowak, 1984; Olszewska, 1997). Another species diagnostic of the Bartonian is *Praesphaerammina subgaleata* Vašíček (Table 1, Fig. 6O, P) (Olszewska *et al.*, 1996; Olszewska, 1997; Golonka and Waśkowska, 2011b). The common occurrence of *Reticulophragmium amplectens* (Grzybowski) in the samples indicates an early Bartonian age of the sediments covering the olistostrome.

Foraminifers in olistoliths

The following three main varieties of shaly olistoliths were sampled for micropalaeontological analysis (Table 1): a non-calcareous, soft to hard, beige-coloured mudstone/claystone (samples CP-9, CPC-10 and CP-11); a non-calcareous, soft, greenish-grey parallel-laminated mudstone (samples CG-5 and CG-6); and a non-calcareous, soft, dark-grey parallel-laminated mudstone/claystone (samples CG-7 and CG-8).

The first category of samples appeared to be barren or contain a very poor foraminifer assemblage (Table 1), with recognizable planktonic forms of *Subbotina* and *Globigerina*-type. The two other categories of samples appeared to contain well-preserved, diversified and abundant microfossils, taxonomically similar and containing DWAF assemblages. Characteristic is the dominance of *Recurvoides*, *Thalmannammina* and *Cribrostomoides* (~30% of all specimens) with numerous occurrences of *Karrerulina conversa* (Grzybowski), *Karrerulina coniformis* (Grzybowski) and *Glomospira charoides* (Jones et Parker) (Table 1, Figs 7G, H, 8R, S). The latter two species are cosmopolitan, but their rich occurrence may indicate the Early Eocene Glomospira div. sp. Zone (Olszewska, 1997). In the Carpathian deep-water realm, such assemblages rich in *Glomospira charoides* (Jurkiewicz, 1967; Waśkowska, 2011) and with a high frequency of *Karrerulina* (Bąk, 2004; Cieszkowski *et al.*, 2011) appeared in the Early Eocene, after the Late Palaeocene Thermal Maximum (LPTM) crisis (e.g., Bubík, 1995; Waśkowska-Oliwa and Leśniak, 2003; Bąk, 2004; Waśkowska-Oliwa, 2005; Chodyń and Waśkowska-Oliwa, 2006; Cieszkowski *et al.*, 2006b, 2011; Waśkowska, 2011).

Fig. 4. Outcrop details showing the chaotic internal structure of the olistostrome. The hammer (scale) is 30 cm long and its head has a length of 17 cm. **A.** Olistoliths of sandy-shaly and shaly flysch in unsorted coarse-grained matrix; note slump-fold relics to the right. **B.** Large intraformational olistolith of sandy-shaly flysch (lower part) and smaller of mudshale and sandstone olistoliths floating in coarse-grained matrix (upper part). **C–E.** Olistoliths of sedimentary rocks in unsorted coarse-grained matrix. **F.** Olistoliths of sandy-shaly flysch with slump-fold relics. **G.** Small sandy and shaly olistoliths scattered in coarse-grained matrix.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Single specimens of *Annectina grzybowskii* (Jurkiewicz) (Fig. 7I), *Glomospira* cf. *diffundens* Cushman et Renz and *Praesphaerammina gerochi* Hanzlíková also were found in the samples (Table 1). Their last occurrence in the Carpathians is known from the Early Eocene deposits (Jednorowska, 1968, 1975; Bąk, 2004; Kaminski and Gradstein, 2005). The same pertains to the forms of *Spiroplectammina navarroana* Cushman, which constitute up to 10% of the foraminifer assemblages in the samples (Table 1, Fig. 8J, L). This taxon occurs frequently in large numbers in the Late Palaeocene–Early Eocene assemblages (Gradstein and Kaminski, 1989; Kuhnt and Kaminski, 1997; Kinsey, 2000; Nagy *et al.*, 2004; Kaminski and Gradstein, 2005), where it co-occurs with numerous *Karrerulina* (Nagy *et al.*, 1997; Kinsey, 2000). Taken together, the foraminifer assemblages in the sampled shaly olistoliths correspond to the Early Eocene.

Foraminifers in olistostrome matrix

Samples of grey to dark-grey, non-calcareous sandy mudstone from the olistostrome matrix (samples MX-12, MX-13, MX-14 and MX-15 in Table 1) contained poorly preserved foraminifer assemblages, with a low number of specimens and low taxonomical diversity. One sample appeared to be barren. Relatively large forms of *Cystammina*/*Ammosphaeroidina* dominate, accompanied by specimens of *Spiroplectammina navarroana* Cushman (Table 1). These species, with relatively large and solid tests, seem to be relics of contemporaneous foraminifer assemblages that were derived by debris flows from the basin floor and sparsely survived the "grinding-mill" conditions of the mass-flow internal shear regime.

DISCUSSION

The composite olistostrome unit embedded in the Hieroglyphic Formation in the Rożnów Lake area constitutes ~50–60% of the formation's local bulk thickness (Cieszkowski *et al.*, 2009b, 2010b, 2012b). The local thickness of the formation (~350 m) exceeds only slightly its general thickness range of 200–300 m (Cieszkowski, 1992; Leszczyński and Radomski, 1994), which suggests that the olistostrome had replaced a significant part of the formation's fine-grained turbiditic deposits. The abundance of large shaly and sandy-shaly olistoliths in the olistostrome unit supports this notion.

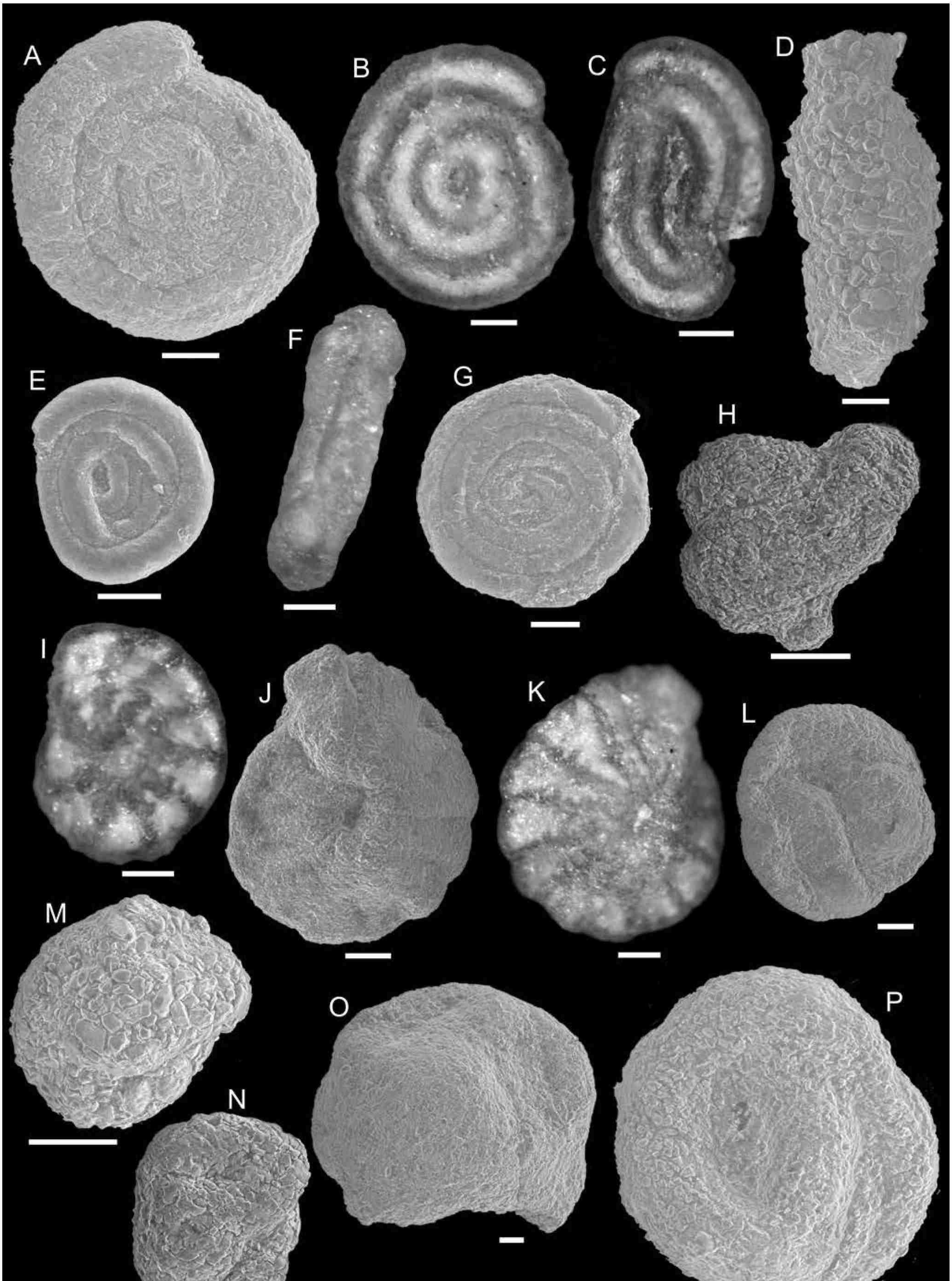
The olistostrome in the Rożnów Lake area, although spectacular in size and clearly representing a major catastrophic event, is by no means unique. The Silesian Nappe contains several such olistostromes of various dimensions, which are particularly large in the western part of the nappe – in the Late Jurassic–Early Cretaceous Vendryně and Hradiště formations (see Jankowski, 2007, 2008; Cieszkowski *et al.*, 2009a, 2012a). Large olistostromes, with olistolith sizes in the range of hundreds to a few thousand metres (olistoplaques), occur also in the Oligocene to Early Miocene formations in the southernmost, inner zone of the Silesian Nappe. Nevertheless, the olistostrome in the Rożnów Lake area is one of the largest documented within the Silesian Nappe and probably the largest known in the Polish sector of the Outer Carpathians.

Biostratigraphical data obtained from the analysis of foraminifers indicate that the emplacement of the olistostrome occurred within the Ammodiscus latus Zone, corresponding to the early Bartonian (or possibly Lutetian/Bartonian transition). The foraminifer assemblages in the fine-grained turbidites directly below and above the olistostrome are similar to those reported earlier from the Green Shales member of the Hieroglyphic Formation in the study area (Cieszkowski, 1992; Cieszkowski and Waśkowska, 2013a) and from the coeval upper part of the formation at other localities in the Silesian Nappe (e.g., Geroch, 1960; Morgiel and Szymakowska, 1978; and references therein).

The olistoliths of greenish-grey and dark-grey non-calcareous mudshales, which dominate in the middle to upper part of the olistostrome, represent deep-water deposits of Early Eocene age. Their foraminifer assemblages abound in agglutinated, flysch-type cosmopolitan forms indicating deposition in a deep-water environment below the CCD. Worth noting is the occurrence of *Spiroplectammina navarroana* Cushman as a significant component of foraminifer assemblages in the shaly olistoliths and present also in the olistostrome matrix. This cosmopolitan species is typical of bathyal environments and unknown from abyssal water depths (see Gradstein and Kaminski, 1989; Kaminski and Gradstein, 2005; and references therein). This taxon is very rare in the Hieroglyphic Formation and in the Silesian, Dukla and Skole nappes, but is relatively common in the Subsilesian Nappe (Geroch, 1960; Morgiel and Szymakowska, 1978; Cieszkowski, 1992), which comprises somewhat shallower flysch (Waśkowska-Oliwa, 2005).

The biostratigraphical evidence indicates that the Hieroglyphic Formation was deposited in an abyssal environment, whereas the muddy deposits resedimented as olistoliths were originally laid down in the Early Eocene at bathyal depth on a slope bounding the abyssal Silesian Basin. The northern vergence of slump folds in the olistoliths indicates olistostrome emplacement from the south, from the northern slope of the Silesian Cordillera that bounded the Silesian Basin in the south. Comparable bathyal deposits are known from the Subsilesian Nappe, which includes slope deposits of the Subsilesian Cordillera that bounded the Silesian Basin in the north (Cieszkowski *et al.*, 2006c). This evidence indicates that muddy bathyal facies were deposited on both sides of the Silesian Basin, on the slopes of the bounding Silesian and Subsilesian cordilleras. These fa-

Fig. 5. Close-up details of small olistoliths in the olistostrome. The hammer (scale) is 30 cm long and its head has a length of 17 cm. **A, E.** Olistoliths of sandy-shaly flysch with relics of slump folds. **B, C.** Olistoliths of sedimentary rocks in unsorted coarse-grained matrix. **D, F.** Subrounded and rounded limestone boulders. **G.** Boulder of granite-gneiss. **H.** Boulder of sandstone derived from the Ciężkowice Fm. **I.** Armoured limestone ball.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cies are poorly preserved and hence have been poorly recognized until now.

The olistostrome in its lower part abounds in sandstone olistoliths that were apparently derived from the underlying Early Eocene Ciężkowice Formation, deposits of a sand-rich base-of-slope turbiditic system (Leszczyński, 1981). The middle part of the olistostrome is dominated by shaly olistoliths, whereas its upper part bears olistoliths of thin- to medium-bedded quartzose turbiditic sandstones with numerous calcareous bioclasts. These sandstones are very similar to the "banded sandstones" described by Leszczyński (1985) from the Hieroglyphic Formation in the adjacent area of Jastrzębia near Ciężkowice. The calcareous component of these sandstones (such as grains of micritic limestone, foraminifer tests, remnants of molluscs, echinoderms, coralline algae and bryozoans) and their carbonate cement indicate deposition in a bathymetric range above the CCD. This interpretation is supported by the microfaunal content of the shale interlayers, which includes calcareous forms of both planktonic and benthonic foraminifers (Cieszkowski, 1992). Planktonic foraminifers are represented by a Middle Eocene assemblage with *Subbotina linaperta* Finaly, *Subbotina yeguaensis* Weinzierl et Applin and *Subbotina eocaena* Guembel (Cieszkowski, 1992). The turbiditic sandstones, resedimented as olistoliths, are thought to have been originally deposited in the middle part of the southern slope of the Silesian Basin, with some of their calcareous detritus derived from the shallower zone of the upper slope or shelf margin. The banded sandstones in the Hieroglyphic Formation have a very limited extent and are known only from the areas of Rożnów Lake and Jastrzębia near Ciężkowice (Cieszkowski *et al.*, 1992; Leszczyński and Radomski, 1994; Cieszkowski and Waśkowska, 2013a). The upper part of the olistostrome contains also occasional olistoliths of Maastrichtian variegated marls, which similarly represent a middle slope depositional environment (Cieszkowski, 1992).

The admixture of subrounded to rounded, coarse gravel-sized exotic debris of Mesozoic limestones (Fig. 5D, F) and crystalline bedrock (Fig. 5G) represents material derived from the structural core of the Silesian Cordillera or its primary gravelly cover. The bedrock core along the cordillera crest must have been locally exposed to erosion by waves or subaerial processes prior to its debris resedimentation.

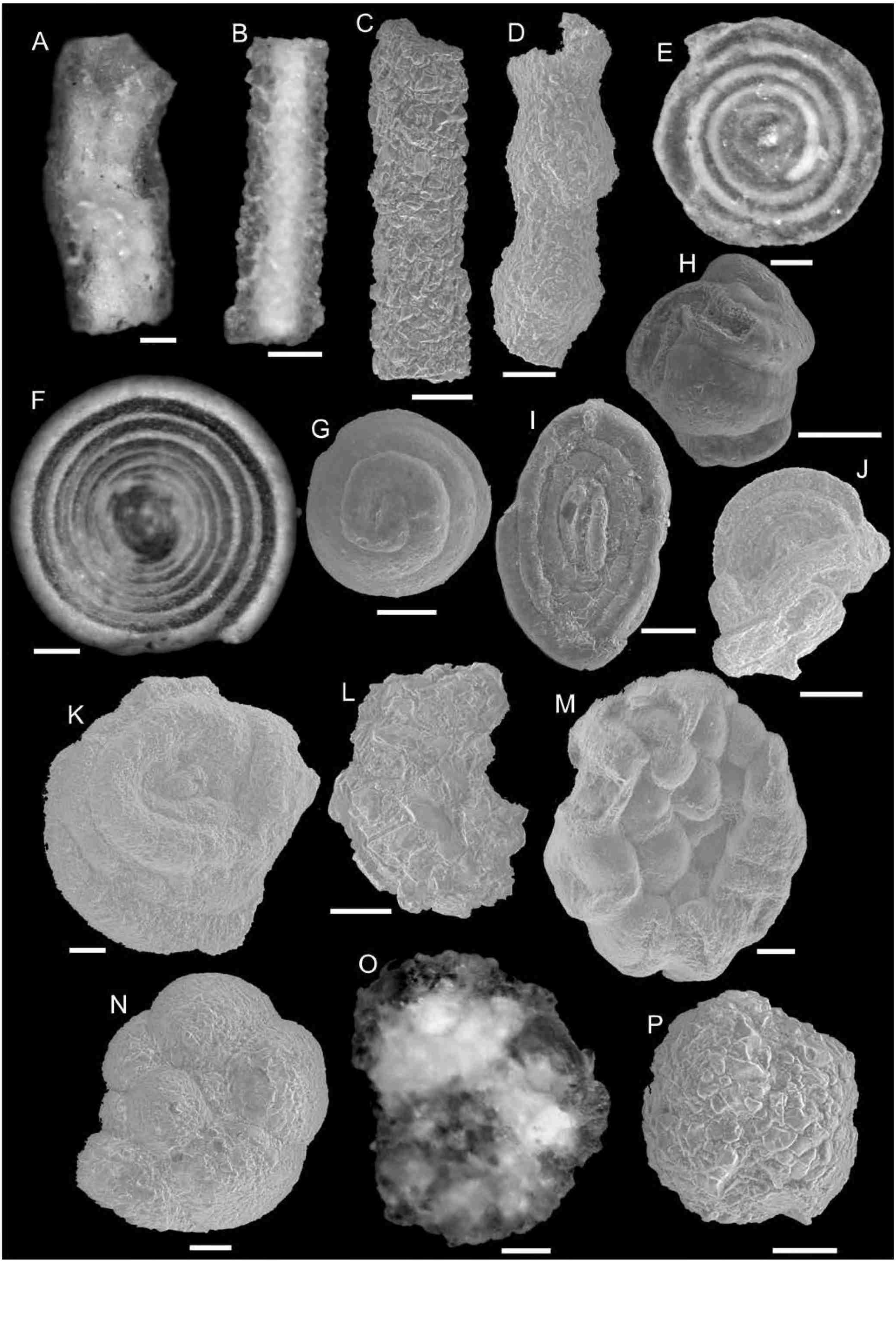
The olistolith composition of olistostromes emplaced in the Silesian Basin may thus provide important information on the bedrock lithology and sedimentary environments of the Silesian Cordillera, which acted as a crucial source area, but was ultimately overridden and deeply buried by the nappes. The composition of olistoliths in the present case also sheds light on the provenance and derivation dynamics of resedimented debris. The compositional tripartition of the olistostrome suggests its emplacement by at least three large consecutive debris flows, which closely followed one another and the deposits of which became amalgamated into a seemingly uniform unit of sedimentary breccia ~200 m thick. The first pulse of resedimentation involved the Early Eocene turbiditic sands of the Ciężkowice Formation, which indicates that these base-of-slope deposits were warped up and destabilized by the thrust-driven uplift and northward migration of the Silesian Cordillera. This tectonic deformation concurrently deepened the synclinal Silesian Basin and established abyssal conditions on its floor. The collapse of the uplifted sands apparently destabilized the former lower-slope Early Eocene muddy flysch, the resedimentation of which then also triggered retrogressive slumping of the Middle Eocene mid-slope "banded" sand-rich flysch. The thrust-related uplift of anticlinal cordillera shed also some exotic Jurassic/Maastrichtian and crystalline rock debris onto the steepened submarine slope. This material, together with contemporaneous Mid-Eocene fine-grained sediment, was incorporated as an admixture in the debris flows.

The submarine slope resedimentation, with the emplacement of bathyal deposits as a composite olistostrome on abyssal basin floor, is thought to have marked the culmination of the second contractional stage of the Outer Carpathians evolution, dated to the Late Cretaceous–Eocene (Cieszkowski *et al.*, 2009a). The accretionary prism at that stage evolved into an array of deepening basins separated by thrust-elevated cordilleras with bathyal slopes and partly emergent crests exposing locally bedrock (Golonka *et al.*, 2013). The Silesian Basin alone accumulated a flysch succession up to 3.5 km thick in Late Cretaceous to Middle Eocene time. The basin-fill succession shows at least three major depositional cycles of shaly or sandy-shaly flysch alternating with thick-bedded, coarse-grained sandy to gravelly flysch (see Książkiewicz, 1962), probably in response to thrusting pulses. The third cycle is represented by deposition of the sandy Ciężkowice Formation (Leszczyński, 1981; Cieszkowski, 1992), succeeded by the sandy-shaly to shaly Hieroglyphic Formation and the calcareous Globigerina Marl Formation. This last cycle appears to have been followed by a culminating episode of large-scale resedimentation that produced the large, composite olistostrome.

CONCLUSIONS

1. The thick (~200 m) and extensive olistostrome embedded in the Mid-Eocene shaly Hieroglyphic Formation of the Silesian Nappe, exposed in the Rożnów Lake area, is tripartite with regard to the composition of its main olistoliths.

Fig. 6. Foraminifers from the "background" shales of the Middle Eocene Hieroglyphic Formation. Microphotographs B, C, I and K were taken in immersion and J in reflected light; the others are SEM images. The scale bar is 100 μm. **A–C.** *Ammodiscus latus* Grzybowski. **D.** *Pseudonodosinella elongata* (Grzybowski). **E.** *Glomospira gordialis* (Jones et Parker). **F.** *Glomospira serpens* (Grzybowski) **G.** *Annectina biedai* Gradstein et Kaminski. **H.** *Glomospira* cf. *irregularis* (Grzybowski). **I–K.** *Reticulophragmium amplectens* (Grzybowski). **L.** *Cystammina* sp. **M.** *Haplopragmoides* cf. *parvulus*. **N.** *Haplophragmoides* sp. **O, P.** *Praesphaerammina subgaleata* Vašíček.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Foraminifer biostratigraphy, combined with comparative sedimentary petrography, has proved to be very useful in identifying the provenance of the olistoliths.

2. The lower part of the olistostrome abounds in olistoliths of turbiditic sandstones derived from the Early Eocene Ciężkowice Formation. The middle part is dominated by olistoliths of Early Eocene (Glomospira div. sp. zone) grey to greenish-grey bathyal mudshales. The upper part contains olistoliths of Middle Eocene turbiditic "banded sandstones", similar to those present locally in the Hieroglyphic Formation and attributed to a bathyal environment above the CCD. The bathyal provenance of olistoliths contrasts with the abyssal muddy environment of the olistostrome emplacement indicated by the foraminifer assemblages of the hosting green shales.

3. The olistostrome unit is inferred to be composite, emplacement by at least three consecutive debris flows in the early Bartonian (Ammodiscus latus Zone). The large debris flows closely followed one another and their deposits became amalgamated by vertical stacking with sediment shear. Biostratigraphical evidence and slump folds in the olistoliths indicate that the olistostrome sediment was derived from the bathyal northern slope of the Silesian Cordillera, which bounded the abyssal Silesian Basin to the south. The uplift and northward movement of thrust-formed cordillera probably warped up the slope-proximal sands of the Ciężkowice Formation, causing their gravitational collapse. This event destabilized the former lower-slope muddy deposits, which then triggered the collapse of mid-slope sandy turbidites in the process of retrogressive slumping.

4. The catastrophic multi-phase emplacement of the spectacular olistostrome marked the last major thrusting pulse of the second stage (Late Cretaceous–Late Eocene) of regional tectonic development of the Outer Carpathian accretionary prism, when cordillera-bounded elongate synclinal basins formed and deeply subsided.

Acknowledgements

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REFERENCES

Bailey, R. H., Skehan, J. W., Dreier, R. B. & Webster, M. J., 1989. Olistostromes of the Avalonian terrane of southeastern New England. In: Horton, J. W. J. & Rast, N. (eds), *Mélanges and Olistostromes of the U.S. Appalachians. Geological Society of America Special Paper*, 228: 93–112.

Bąk, K., 2004. Deep-water agglutinated foraminiferal changes across the Cretaceous/Tertiary and Paleocene/Eocene transitions in the deep flysch environment; eastern Outer Carpathians (Bieszczady Mts, Poland). In: Bubík, M. & Kaminski, M. A. (eds), *Proceedings of the Sixth International Workshop on Agglutinated Foraminifera. Grzybowski Foundation Special Publication*, 8: 1–56.

Bubík, M., 1995. Cretaceous to Paleogene agglutinated foraminifera of the Bílé Karpaty unit (West Carpathians, Czech Republic). In: Kaminski, M. A., Geroch, S. & Gasiński, M. A. (eds), *Proceedings of the Fourth International Workshop on Agglutinated Foraminifera. Grzybowski Foundation Special Publication*, 3: 71–116.

Burtan, J. & Skoczylas-Ciszewska, K., 1964. *Szczegółowa mapa geologiczna Polski, region Karpat i Przedgórza, Wydanie tymczasowe, 1: 50 000, Arkusz Męcina*. Wydawnictwa Geologiczne, Warszawa.

Callot, P., Sempere, T., Odonne, F. & Robert, E., 2008. Giant submarine collapse of a carbonate platform at the Turonian–Coniacian transition: The Ayabacas Formation, southern Peru. *Basin Research*, 20: 333–357.

Chodyń, R. & Waśkowska-Oliwa, A., 2006. Lithostratigraphy and biostratigraphy of the Paleocene–Early Oligocene flysch sediments in the western part of the Szczyrzyc Synclinorium, Silesian Nappe (Polish Outer Carpathians). In: Sudar, M., Ercegovac, M. & Grubić, A. (eds), *Proceedings 18th Congress of the Carpathian Balkan Geological Association: Scientific Annals of the School of Geology. Aristole University of Thessaloniki, Belgrade, Serbia, Special Volume*, 100: 57–60.

Cieszkowski, M., 1992. Michalczowa zone: a new unit of Fore-Magura Zone, Outer Carpathians, south Poland. *Kwartalnik AGH Geologia*, 18: 1–125. [In Polish, with English summary.]

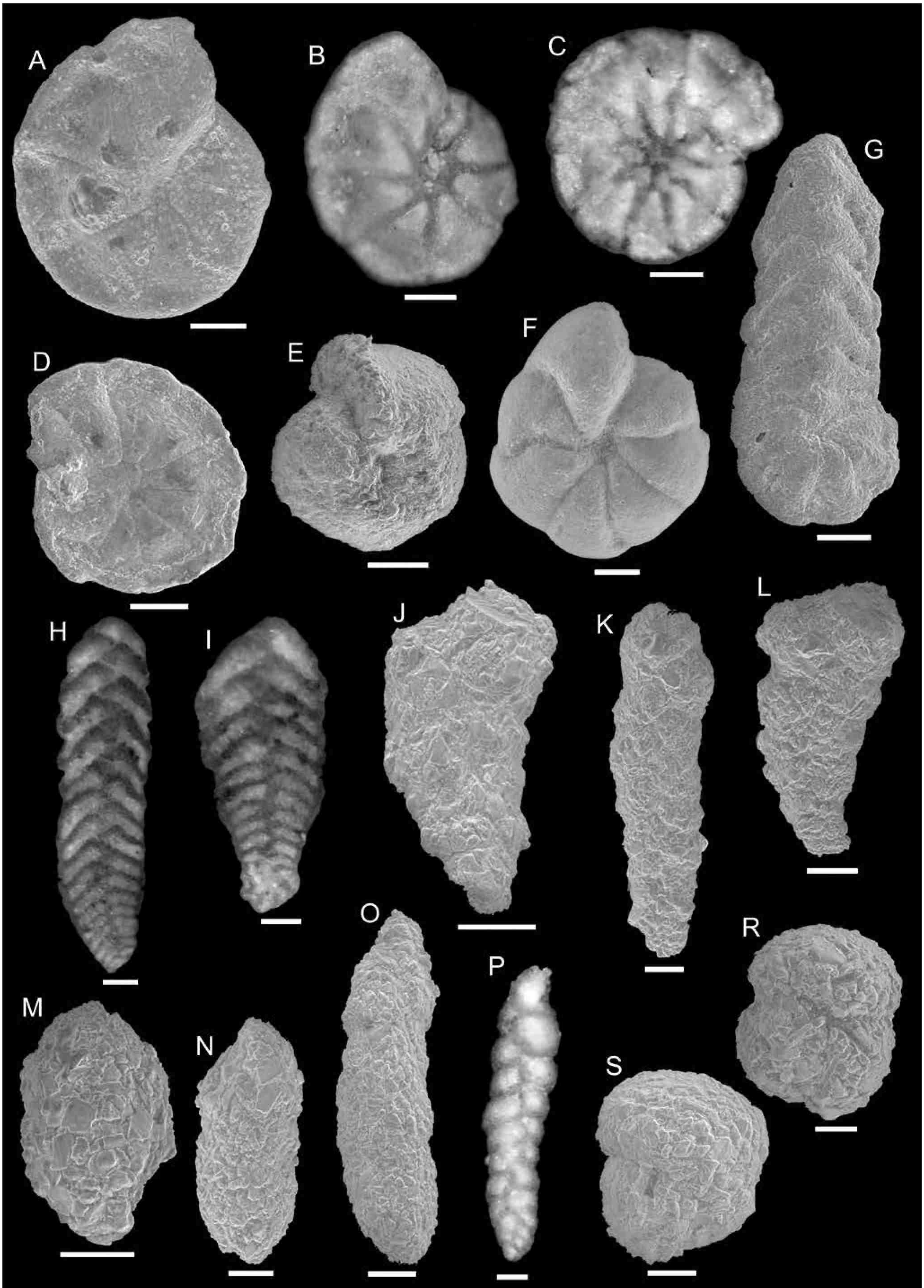
Cieszkowski, M., 1999. Stop 3, Lipie. Olistostroms in the Inner Zone of the Silesian Nappe – Symptoms of tectonic activity at the northern margin of the Silesian Ridge. In: *Proceedings of the 5th Carpathian Tectonic Workshop (Poprad-Szymbark)*. Institute of Geological Sciences, Polish Academy of Sciences, Kraków, pp. 19–21.

Cieszkowski, M., Dziubińska, B. & Ślączka, A., 2006a. Serpentynite of Kilb (Northern Zone, Austria): a new insight into its mineralogy. In: Sudar, M., Ercegovac, M. & Grubić, A. (eds), *Proceedings 18th Congress of the Carpathian Balkan Geological Association: Scientific Annals of the School of Geology. Aristole University of Thessaloniki, Belgrade, Serbia, Special Volume*, 100: 66–71.

Cieszkowski, M. & Golonka, J., 2006. Olistostromes as indicators of the geodynamic process (Northern Carpathians). *Geolines*, 20: 27–28.

Cieszkowski, M., Golonka, J., Krobicki, M., Ślączka, A., Oszczypko, N. & Waśkowska-Oliwa, A., 2008a. Origin of olistostroms in different stages of the Northern Carpathians evolution. In: Jankowski, L. (ed.), Kompleksy chaotyczne Karpat polskich. Conference Proceedings. Państwowy Instytut Geologiczny, Warszawa, pp. 24–26.

Fig. 7. Foraminifers from the olistostrome olistoliths. Microphotographs A, B, E, F and O were taken in immersion and the others are SEM images. The scale bar is 100 μm. **A.** *Bathysiphon* sp. **B, C.** *Psammosiphonella cylindrica* (Glaessner). **D.** *Reophax* sp. **E.** *Ammodiscus tenuissimus* Grzybowski. **F.** *Ammodiscus cretaceous* (Reuss). **G, H.** *Glomospira charoides* (Jones et Parker). **I.** *Annectina grzybowskii* (Jurkiewicz). **J, K.** *Glomospira* sp. **L.** *Popovia* sp. **M.** *Paratrochamminoides deflexiformis* (Noth). **N.** *Paratrochamminoides* sp. **O.** *Popovia* cf. *beckmanni* (Kaminski et Gradstein). **P.** *Recurvoides nucleolus* (Grzybowski).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Cieszkowski, M., Golonka, J., Krobicki, M., Ślączka, A., Oszczypko, N. & Waśkowska-Oliwa, A., 2008b. Origin of olistoliths in alternating evolutionary stages of the Northern Outer Carpathians, Poland. *Mineralia Slovaca Geovestnik*, 3–4: 232–233.

Cieszkowski, M., Golonka, J., Krobicki, M., Ślączka, A., Oszczypko, N., Waśkowska, A. & Wendorff, M., 2009a. The Northern Carpathian plate tectonic evolutionary stages and origin of olistoliths and olistostromes. *Geodinamica Acta*, 22: 101–126.

Cieszkowski, M., Golonka, J., Krobicki, M., Ślączka, A., Waśkowska, A. & Wendorff, M., 2009b. Olistoliths within the Silesian Series and their connections with evolutionary stages of the Silesian Basin. *Kwartalnik AGH Geologia*, 35: 13–21. [In Polish, with English summary.]

Cieszkowski, M., Golonka, J., Nigro, F., Renda, P. & Ślączka, A., 2010a. Sedimentary basins evolution and olistolith formation: the cases of Carpathian and Sicilian regions. In: *Abstracts Volume, 19th Congress of Carpathian-Balkan Geological Association (Thessaloniki). Geologica Balcanica*, 39: 76–77.

Cieszkowski, M., Golonka, J., Ślączka, A. & Waśkowska, A., 2010c. Walory geologiczne melsztyńskiego Wzgórza Zamkowego i jego otoczenia (Karpaty Zewnętrzne). In: Rajchel, J. (ed.), *Jubileusz Katedry Geologii Ogólnej, Ochrony Środowiska i Geoturystyki Akademii Górniczo-Hutniczej 1920–2010.* Wydawnictwa AGH, Kraków, pp. 109–120.

Cieszkowski, M., Golonka, J., Ślączka, A., & Waśkowska, A., 2012b. Role of the olistostromes and olistolith in tectonostratigraphic evolution of the Silesian Basin in the Outer West Carpathians. *Tectonophysics*, 568–569: 248–265.

Cieszkowski, M., Golonka, J. & Waśkowska, A., 2012a. An olistolith interpretation for the Paleocene Szydłowiec sandstones in the stratotype area (Outer Carpathians, Poland). *Austrian Journal of Earth Sciences*, 105: 240–247.

Cieszkowski, M., Golonka, J. & Waśkowska-Oliwa, A., 2006c. Tectonics and tectonic evolutionary stages of the Subsilesian Realm, Outer Carpathians. In: Sudar, M., Ercegovac, M. & Grubić, A. (eds), *Proceedings 18th Congress of the Carpathian Balkan Geological Association: Scientific Annals of the School of Geology. Aristole University of Thessaloniki, Belgrade, Serbia, Special Volume*, 100: 72–74.

Cieszkowski, M., Golonka, J., Waśkowska-Oliwa, A. & Chodyń, R., 2007. Type locality of the Mutne Sandstone Member of the Jaworzynka Formation, Western Outer Carpathians, Poland. *Annales Societatis Geologorum Poloniae*, 77: 269–290.

Cieszkowski, M., Koszarski, A., Leszczyński, S., Michalik, M., Radomski, A. & Szulc, L., 1991. *Szczegółowa mapa geologiczna Polski 1:50000, Arkusz Ciężkowice.* Państwowy Instytut Geologiczny, Warszawa.

Cieszkowski, M., Leśniak, T., Środoń, J. & Waśkowska-Oliwa, A., 2006b. Bentonitized tuffites in the Lower Eocene deposits of the Subsilesian Unit (Western Outer Carpathians, Poland). *Annales Societatis Geologorum Poloniae*, 76: 197–214.

Cieszkowski, M., Malata, E., Oszczypko, N., Pescatore, T. S., Senatore, M. R., Ślączka, A. & Valente, A., 1994. Deep sea clastic sediments and associated megaturbidites and oliostostromes (Cenozoic, Cilento, Southern Italy). In: Carananante, G. & Tonielli, R. (eds), *Pre-Meeting Fieldtrip Guidebook, 15th IAS Regional Meeting (Ischia). Publishing House De Frede*, Napoli, pp. 191–220.

Cieszkowski, M., Oszczypko, N., Pescatore, T. S., Ślączka, A., Senatore, M. R. & Valente, A., 1995. Megatorbiditi calcareomarnose nelle succesioni fliscioidi dell'Apennino meridionale (Cilento, Italia) e dei Carpazi settentrionali (Polonia). *Bollettino della Società Geologica Italiana*, 114: 67–88.

Cieszkowski, M., Ślączka, A., & Waśkowska, A., 2010b. Eocene olistostrome in the Silesian Nappe at the shore of Rożnów Lake, Outer Carpathians, Poland. *Mineralia Slovaca, Geovestník*, 42: 508.

Cieszkowski, M., Ślączka, A. & Wdowiarz, S., 1985. New data on structure of the flysch Carpathians. *Przegląd Geologiczny*, (33)6: 313–333.

Cieszkowski, M. & Waśkowska, A., 2010. Castles the Rożnów and Czchów lakes area as geoturistic lapidarium and role of the Istebna Sandstones in their construction. *Geoturystyka*, 21: 3–18. [In Polish, with English summary.]

Cieszkowski, M. & Waśkowska, A., 2013a. Olistostrome deposits in the Eocene Hieroglyphic Formation (Silesian Nappe, Outer Carpathians). In: Bąk, M., Kowal-Kasprzyk, J., Waśkowska, A. & Kaminski, M. A. (eds), *Abstracts Volume, 14th Czech-Slovak-Polish Paleontological Conference and 9th Micropaleontological Workshop. Grzybowski Foundation Special Publication*, 19: 10–11.

Cieszkowski, M. & Waśkowska, A., 2013b. Olistostrome deposits in the Eocene Hieroglyphic Formation (Silesian Nappe, Outer Carpathians). In: Broska, I. & Tomašových, A. (eds), *Abstracts Book, Geological Evolution of the Western Carpathians: New Ideas in the Field of Inter-Regional Correlations.* Geological Institute, Slovak Academy of Sciences, Bratislava, pp. 42–43.

Cieszkowski, M., Waśkowska, A. & Kaminski, M. A., 2011. Deep-water agglutinated foraminifera in Paleogene hemi-pelagic sediments of the Magura Basin in the Sucha Beskidzka area – variegated shales of the Łabowa Shale Formation. In: Bąk, M., Kaminski, M. A. & Waśkowska, A. (eds), *Integrating Microfossil Records from the Oceans and Epicontinental Seas. Grzybowski Foundation Special Publication*, 17: 53– 63.

Folk, R. L., 1974. *Petrology of Sedimentary Rocks.* Hemphill, Austin, TX, 182 pp.

Geroch, S., 1960. Microfaunal assemblages from the Cretaceous and Palaeogene Silesian unit in the Beskid Śląski Mts. Western Carpathians. *Biuletyn Instytutu Geologicznego*, 153: 1–138. [In Polish, with English summary.]

Geroch, S. & Gradziński, R. 1955. Stratigraphy of the Sub-Silesian series in the tectonic window of Żywiec (Western Carpathians). *Rocznik Polskiego Towarzystwa Geologicznego*, 24: 3–62. [In Polish, with English summary.]

Geroch, S., Jednorowska, A., Książkiewicz, M. & Liszkowa, J., 1967. Stratigraphy based upon microfauna in the Western Polish Carpathians. *Biuletyn Instytutu Geologicznego*, 211: 185–282.

Geroch, S. & Nowak, W., 1984. Proposal of zonation for the late Tithonian–late Eocene, based upon arenaceous Foraminifera from the Outer Carpathians, Poland. In: Oertli, H. J. (ed.),

Fig. 8. Foraminifers from the olistostrome olistoliths. Microphotographs B, C, H, I and P were taken in immersion and the others are SEM images. The scale bar is 100 μm. **A, B.** *Haplophragmoides walteri* (Grzybowski). **C, D.** *Haplophragmoides* cf. *nauticus* Kender *et al.* **E.** *Haplophragmoides kirki* Wickenden. **F.** *Haplopragmoides/Reticulophragmium* sp. **G–I.** *Spiroplectammina spectabilis* (Grzybowski). **J–L.** *Spiroplectammina navarroana* Cushman. **M, N.** *Karrerulina coniformis* (Grzybowski). **O, P.** *Karrerulina conversa* (Grzybowski). **R, S.** *Trochammina* sp. (dorsal and ventral side).

Benthos '83, Proceedings of 2nd International Symposium on Benthic Foraminifera (Pau). Elf Aquitaine, Pau, pp. 225–239.

Golonka, J., Aleksandrowski, P., Aubrecht, M., Chowaniec, J., Chrustek, M., Cieszkowski, M., Florek, R., Gawęda, A., Jarosiński, M., Kępińska, B., Krobicki, M., Lefeld, J., Lewandowski, M., Marko, F., Michalik, M., Oszczypko, N., Picha, F., Potfaj, M., Słaby, E., Ślączka, A., Stefaniuk, M., Uchman, A. & Żelaźniewicz, A., 2005. The Orava Deep Drilling Project and post-Paleogene tectonics of the Northern Carpathians. *Annales Societatis Geologorum Poloniae*, 75: 211–248.

Golonka, J., Gahagan, L., Krobicki, M., Marko, F., Oszczypko, N. & Slaczka, A., 2006. Plate tectonic evolution and paleogeography of the circum-Carpathian region. In: Golonka, J. & Picha, F. (eds), *The Carpathians and their Foreland: Geology and Hydrocarbon Resources. American Association of Petroleum Geologists Memoir*, 84: 11–46.

Golonka, J., Ślączka, A., Waśkowska, A., Krobicki, M. & Cieszkowski, M., 2013. Budowa geologiczna zachodniej części polskich Karpat zewnętrznych. In: Krobicki, M. & Feldman-Olszewska, A. (eds), *Głębokomorska sedymentacja fliszowa – sedymentologiczne aspekty historii basenów karpackich. Polska Konferencja Sedymentologiczna POKOS 5 (Żywiec)*. Państwowy Instytut Geologiczny – Państwowy Instytut Badawczy, Warszawa , pp. 11– 62. [In Polish.]

Golonka, J. & Waśkowska, A., 2011a. The Zembrzyce Shale Member of the Beskid Makowski Formation in the Babica area (Siary Zone of the Magura Nappe, Polish Outer Carpathians); the *Haplophragmoides parvulus* Blaicher type locality. In: Bąk, M., Kaminski, M. A. & Waśkowska, A. (eds), *Integrating Microfossil Records from the Oceans and Epicontinental Seas. Grzybowski Foundation Special Publication*, 17: 37–44.

Golonka, J. & Waśkowska, A., 2011b. The Beloveža Formation of the Rača Unit, Magura Nappe, in the Beskid Wysoki Mts (Polish Outer Carpathians) north of Babia Góra Mountain – monospecific assemblages with *Praesphaerammina subgaleata* (Vašíček). In: Bąk, M., Kaminski, M. A. & Waśkowska, A. (eds), *IntegratingMicrofossil Records from the Oceans and Epicontinental Seas. Grzybowski Foundation Special Publication*, 17: 27–35. [In Polish.]

Golonka, J. & Waśkowska, A., 2012. The Beloveža Formation of the Raca Unit in the Beskid Niski Mts. (Magura Nappe, Polish Flysch Carpathians) and adjacent parts of Slovakia and their equivalents in the western part of the Magura Nappe; remarks on the Beloveža Formation–Hieroglyphic Beds controversy. *Geological Quarterly*, 56: 821–832.

Golonka, J. & Waśkowska-Oliwa, A., 2007. Stratigraphy of the Polish Flysch Carpathians between Bielsko-Biała and Nowy Targ. *Kwartalnik AGH Geologia*, 33: 5–28. [In Polish, with English summary.]

Gradstein, F. M. & Kaminski, M. A., 1989. Taxonomy and biostratigraphy of new emended species of Cenozoic deep-water agglutinated foraminifera from the Labrador and North Seas. *Micropaleontology*, 35: 72–92.

Jankowski, L., 2007. Chaotic complexes in Gorlice region (Polish Outer Carpathians). *Biuletyn Państwowego Instytutu Geologicznego*, 426: 27–52. [In Polish, with English summary.]

Jankowski, L., 2008. Kompleksy chaotyczne Karpat polskich. In: *Materiały Konferencji Terenowej Kraków–Polańczyk*. Państwowy Instytut Geologiczny, Warszawa, pp. 24–26. [In Polish.]

Jednorowska, A., 1968. Mikrofauna brzeżnych jednostek płaszczowiny magurskiej i jej znaczenie stratygraficzne. *Prace Geologiczne Polskiej Akademii Nauk*, 50: 7–89. [In Polish, with Russian and French summaries.]

Jednorowska, A., 1975. Small foraminiferal assemblages in the Paleocene of the Polish Western Carpathians. *Studia Geologica Polonica*, 67: 1–149. [In Polish, with English summary.]

Jurkiewicz, H., 1967. Foraminifers in the Sub-Menilitic Palaeogene of the Polish Middle Carpathians. *Biuletyn Instytutu Geologicznego*, 210: 5–128. [In Polish, with English summary.]

Kaminski, M. A. & Gradstein, F. M., 2005. *Atlas of Paleogene Cosmopolitan Deep-water Agglutinated Foraminifera. Grzybowski Foundation Special Publication*, 10, 547 pp.

Kinsey, I. S., 2000. Palaeogene benthic foraminiferal biostratigraphy of the Halten Terrace area, Norway. In: Hart, M. B., Kaminski, M. A. & Smart, C. W. (eds), *Proceedings of the Fifth International Workshop on Agglutinated Foraminifera. Grzybowski Foundation Special Publication*, 7: 221–241.

Koszarski, L., 1966. *Szczegółowa mapa geologiczna Polski, Region Karpat i Przedgórza, Wydanie tymczasowe, 1: 50 000, Arkusz Rzepiennik*. Wydawnictwa Geologiczne, Warszawa.

Koszarski, L., Kuciński,T. & Szymakowska, F., 1964. *Szczegółowa mapa geologiczna Polski, Region Karpat i Przedgórza, Wydanie tymczasowe, 1: 50 000, Arkusz Pilzno*. Wydawnictwa Geologiczne, Warszawa.

Koszarski, J., Sikora, W. & Wdowiarz, S., 1974. The flysch Carpathians. In: Maheľ, M. (ed.), *Tectonics of the Carpathian-Balkan Regions, Explanations to the Tectonic Map of the Carpathian-Balkan Regions and their Foreland*. Štátny geologický ústav Dionýza Štúra, Bratislava, pp. 180–197.

Koszarski, L. & Żytko, K., 1966. *Szczegółowa mapa geologiczna Polski, Region Karpat i Przedgórza, Wydanie tymczasowe, 1: 50 000, Arkusz Jasło*. Wydawnictwa Geologiczne, Warszawa.

Kotlarczyk, J., 1988. Potok Makówka na S od Gruszowa (ogniwo z Leszczyn, formacja z Ropianki); okruchowiec osuwiskowy z Makówki i olistolity margli z Węgierki. In: Kotlarczyk, J. (ed.), *Materiały 59. Zjazdu Polskiego Towarzystwa Geologicznego (Przemyśl)*. Wydawnictwa AGH, Kraków, pp. 72–75.

Książkiewicz, M., 1958. Submarine slumping in the Carpathian Flysch. *Annales Societatis Geologorum Poloniae*, 28: 123–151.

Książkiewicz, M. (ed.), 1962. *Geological Atlas of Poland: Stratigraphic and Facies Problems* [with 16 maps]. Wydawnictwa Geologiczne, Warszawa.

Książkiewicz, M., 1965. Les cordilleres dans les mers crétacées et paléogènes des Carpathes du Nord. *Bulletin de la Société Géologique de France*, 7: 75–97.

Książkiewicz, M., 1977. The tectonics of the Carpathians. In: Pożaryski, W. (ed.), *Geology of Poland, Volume IV, Tectonics*. Wydawnictwa Geologiczne, Warszawa, pp. 476–620.

Kuciński, T., 1965. *Szczegółowa mapa geologiczna Polski, Region Karpat i Przedgórza, Wydanie tymczasowe, 1: 50 000, Arkusz Tuchów*. Wydawnictwa Geologiczne, Warszawa.

Kuhnt, W. & Kaminski, M. A., 1997. Cenomanian to lower Eocene deep-water agglutinated foraminifera from the Zumaya Section, Northern Spain. *Annales Societatis Geologorum Poloniae*, 67: 257–270.

Leszczyński, S., 1981. Ciężkowice Sandstones of the Silesian Unit in Polish Carpathians: a study of deep-water coarse-clastic sedimentation. *Annales Societatis Geologorum Poloniae*, 51: 435–502 [In Polish, with English summary.]

Leszczyński, S., 1985. Banded sandstones of the Hieroglyphic Beds at Jastrzębia near Ciężkowice. *Kwartalnik Geologiczny*, 29: 395–403. [In Polish, with English summary.]

Leszczyński, S. & Radomski, A., 1994. *Objaśnienia do szczegó-*

łowej mapy geologicznej Polski w skali 1:50 000, Arkusz Ciężkowice. Wydawnictwa Geologiczne, Warszawa, 82 pp. [In Polish.]

Liszkowa, J., 1956. Microfauna of the sub-Silesian series. *Przegląd Geologiczny*, 4: 463–469. [In Polish, with English summary.]

Lowe, D. R., 1982. Sediment gravity flows, II. Depositional models with special reference to the deposits of high-density turbidity currents. *Journal of Sedimentary Research*, 52: 279–297.

Lucente, C. C. & Pini, G. A., 2008. Basin-wide mass-wasting complexes as markers of the Oligo–Miocene foredeep–accretionary wedge evolution in the Northern Apennines, Italy. *Basin Research*, 20: 49–71.

Maheľ, M. (ed.), 1974. *Tectonics of the Carpathian-Balkan Regions: Explanations to the Tectonic Map of the Carpathian-Balkan Regions and their Foreland.* Štátny geologický ústav Dionýza Štúra, Bratislava, 488 pp.

Morgiel, J. & Olszewska, B., 1981. Biostratigraphy of the Polish External Carpathians based on agglutinated foraminifera. *Micropaleontology*, 27: 1–30.

Morgiel, J. & Szymakowska, F., 1978. Paleocene and Eocene stratigraphy of the Skole Unit. *Biuletyn Instytutu Geologicznego*, 310: 39–71. [In Polish, with English summary.]

Nagy, J., Kaminski, M. A., Johnsen, K. & Mitlehner, A. G., 1997. Foraminiferal, palynomorph, and diatom biostratigraphy and paleoenvironments of the Torsk Formation: A reference section for the Paleocene–Eocene transition in the western Barents Sea. In: Hass, E. & Kaminski, M. A. (eds), *Micropaleontology and Paleoceanography of the Northern North Atlantic. Grzybowski Foundation Special Publication*, 5: 15–38.

Nagy, J., Kaminski, M. A., Gradstein, F. M. & Johnson, K., 2004. Quantitative foraminiferal and palynomorph biostratigraphy of the Paleogene in the southwestern Barents Sea Department of Geology. In: Bubík, M. & Kaminski, M. A. (eds), *Proceedings of the Sixth International Workshop on Agglutinated Foraminifera. Grzybowski Foundation Special Publication*, 8: 359–379.

Naylor, M. A., 1981. Debris flow (olistostromes) and slumping on a distal passive continental margin: the Palombini limestone-shale sequence of the northern Apennines. *Sedimentology*, 28: 837–852.

Olszak, J., 2006. Synsedimentary slumping in fold-and-thrust system of the Magura Zone: Evidence from olistoliths in the Beloveža formation (Zbludza area, Poland). *Geologica Carpathica*, 57: 177–184.

Olszewska, B., 1997. Foraminiferal biostratigraphy of the Polish Outer Carpathians: A record of basin geohistory. *Annales Societatis Geologorum Poloniae*, 67: 325–337.

Olszewska, B., Odrzywolska-Bieńkowa, E., Giel, M. D., Pożaryska, K. & Szczechura, K., 1996. *Foraminiferida* Eichwald, 1830. In: Limanowska, L. & Piwocki, M. (eds), *Geology of Poland. Atlas of Characteristic Fossils, Volume III, Part 3a: Paleogene.* Państwowy Instytut Geologiczny, Warszawa, pp. 45–215.

Oszczypko, N. & Ślączka, A., 1987. Olistostromes and over-thrusting in Polish Carpathians. *Annales Instituti Geologici Publici Hungarici*, 70: 282–292.

Pescatore, T., Senatore, M. R., Cieszkowski, M., Ślączka, A. & Potfaj, M., 2010. On a comparison of olistostromes and olistoliths from the Cilento Flysch (Southern Apennines, Italy) and the Northern Carpathians (Poland, Slovakia). In: *Abstracts Volume, 19th Congress of Carpathian-Balkan Geol o-gical Association (Thessaloniki). Geologica Balcanica*, 39: 303–304.

Polak, A., 1999. Budowa geologiczna płaszczowiny śląskiej w okolicy Skrzydlnej. *Przegląd Geologiczny*, 8: 753–764. [In Polish, with English abstract.]

Rajchel, J., 2004. Egzotyki wapieni litotamniowych z iłów babickich jednostki skolskiej Karpat polskich. In: Krobicki, M. (ed.), *Egzotyki karpackie – znaczenie w rekonstrukcji paleogeograficzno-geotektonicznych. Materiały ogólnopolskiego seminarium (Kraków).* Akademia Górniczo-Hutnicza, Wydział Geologii, Geofizyki i Ochrony Środowiska, Kraków, pp. 47–49. [In Polish.]

Raymond, L. A., 1978. A classification of melanges and broken formations. *Geological Society of America Abstracts with Program*, 10: 143.

Richter, D., 1975. Olistostrome, olistolith, olistothrymma and olistoplaka as criteria of gravitational mass movements and resedimentation in geosynclinal areas. *Bollettino dell Servizio Geologico del Italia*, 96: 371–417.

Sokołowski, S., 1935. Geologia doliny Dunajca między Tropiem a Kurowem. *Kosmos A*, 60: 49–93. [In Polish.]

Stow, D. A. V. & Shanmugam, G., 1980. Sequence of structures in fine-grained turbidites: comparison of recent deep-sea and ancient flysch sediments. *Sedimentary Geology*, 25: 23–42.

Szymakowska, F., 1966. Outliers of the Magura nappe in the Jasło area and their relations with the Fore-Magura series. *Annales Societatis Geologorum Poloniae*, 36: 41–63. [In Polish, with English summary.]

Szymakowska, F., 1976. Olistostromes in the Krosno Beds (Polish Carpathians). *Annales Societatis Geologorum Poloniae*, 46: 39–50. [In Polish, with English summary.]

Szymakowska, F., 1981. Olistostromes in the Krosno Beds of the Strzyżów Depression (Polish Carpathians). *Studia Geologica Polonica*, 68: 75–87. [In Polish, with English summary.]

Ślączka, A., 1964. Geological structure of the Silesian Unit between Bilsko and Tabaszowa. *Kwartalnik Geologiczny*, 8: 199–210. [In Polish, with English summary.]

Ślączka, A.& Gasiński, M. A., 1985. Palaeobathymetric model of the Upper Senonian flysch sediments of a part of the Silesian Basin (Polish Carpathians). *Cretaceous Research*, 6: 207–218.

Ślączka, A. & Golonka, J., 2006. Remarks on evolution of junction of West and East Outer Carpathians and on the Bukowiec Ridge. In: Sudar, M., Ercegovac, M. & Grubić, A. (eds), *Proceedings 18th Congress of the Carpathian Balkan Geological Association: Scientific Annals of the School of Geology. Aristole University of Thessaloniki, Belgrade, Serbia, Special Volume*, 100: 558–561.

Ślączka, A., Hoeck, V. & Ionescu, C., 2011. Mesozoic slope-aprons and slope fans in the Tauern Window (Austria). *Austrian Journal of Earth Sciences*, 104: 58–72.

Ślączka, A. & Kaminski, M. A., 1998. *A Guidebook to Excursions in the Polish Flysch Carpathians. Grzybowski Foundation Special Publication*, 6, 171 pp.

Ślączka, A., Renda, P., Cieszkowski, M., Golonka, J. & Nigro, F., 2012. Sedimentary basin evolution and olistolith formation: The case of Carpathian and Sicilian region. *Tectonophysics*, 568–569: 306–319.

Waśkowska, A., 2011. Response of Early Eocene deep-water benthic foraminifera to volcanic ash falls in the Polish Outer Carpathians. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 305: 50–64.

Waśkowska, A., Golonka, J., Strzeboński, P., Krobicki, M., Vašíček, Z. & Skupien P, 2009. Early Cretaceous deposits of the proto-Silesian Basin in Polish–Czech Flysch Carpathians. *Kwartalnik AGH Geologia*, 33: 39–47. [In Polish, with English summary.]

Waśkowska-Oliwa, A., 2005. Foraminiferal paleodepth indicators from the lower Palaeogene deposits of the Subsilesian Unit (Polish Outer Carpathians). *Studia Geologica Polonica*, 124: 297–324.

Waśkowska-Oliwa, A. & Leśniak, T., 2003. Biostratigratigraphy and palaeoecology of Early Palaeogene deep water foraminiferal assemblages from the Subsilesian Unit in the Żywiec tectonic window (Polish Outer Carpathians). *Bulletin of the Polish Academy of Sciences*, 51:11–27.

Wendorff, M., 2005a. Evolution of Neoproterozoic–Lower Palaeozoic Lufilian arc, Central Africa: A new model based on syntectonic conglomerates. *Journal of the Geological Society of London*, 162: 5–8.

Wendorff, M., 2005b. Lithostratigaphy of Neoproterozoic syn-rift sedimentary megabreccia from Mwambashi, Copperbelt of Zambia, and correlation with olistostrome succession from Mufulira. *South African Journal of Geology*, 108: 505–524.

Wendorff, M., 2011. Tectonosedimentary expressions of the evolution of the Fungurume foreland basin in the Lufilian Arc, Neoproterozoic–Lower Palaeozoic, Central Africa. In: van Hinsbergen, D., Buiter, S., Torsvik, T., Gaina, C. & Webb, S. (eds), *Out of Africa: A Synopsis of 3.8 Ga of Earth History. Geological Society of London Special Publication*, 357: 69–83.

Żytko, K., Gucik, S., Oszczypko, N., Zając, R., Garlicka, I., Nemčok, J., Eliaš, M., Menčik, E., Dworak, J., Stranik, Z., Rakuš, M. & Matejovska, O., 1989. Geological map of the Western Outer Carpathians and their foreland without Quaternary formations. In: Poprawa, D. & Nemčok, J. (eds), *Geological Atlas of the Western Carpathians and their Foreland.* Państwowy Instytut Geologiczny, Warszawa.