Geological Quarterly, 2016, **60** (2): 301–316
DOI: http://dx.doi.org/10.7306/gq.1264

Deep-sea mass-flow sediments and their exotic blocks from the Ropianka Formation (Campanian–Paleocene) in the Skole Nappe: a case study of the Wola Rafałowska section (SE Poland)

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Łapcik, P., Kowal-Kasprzyk, J., Uchman, A., 2016. Deep-sea mass-flow sediments and their exotic blocks from the Ropianka Formation (Campanian–Paleocene) in the Skole Nappe: a case study of the Wola Rafałowska section (SE Poland). Geological Quarterly, **60** (2): 301–316, doi: 10.7306/gq.1264

Flysch deposits of the Ropianka Formation (Wiar and Leszczyny members; Skole Nappe) at Wola Rafałowska include two different sediments that contain exotic pebbles, cobbles and boulders. The first one is a graded conglomerate that contains mostly cobbles of sandstones, gneisses, Štramberk-type limestones, volcanic rocks, pegmatites and ferruginous siltstones. The second one is a pebbly mudstone that contains clasts of sandstones, stone coal, grey mudstones, volcanic rocks, schists, limestones, marls, black mudstones, conglomerates, volcaniclastic rocks and quartz gravels that are floating within a muddy matrix. Genesis of the conglomerate is unclear because it shows features typical of debris flows (poorly sorted, matrix- to clast-supported, large amount of cobble to boulder fraction) as well as high density turbiditic currents (indistinct normal gradation, small amount of cohesive material, crushed clasts that suggest interaction between grains during transportation and at least partly turbulence during flow). The pebbly mudstone represents typical debris flow deposits (large amount of cohesive material, matrix-supported, poorly sorted, lack of grain gradation and traction structures that suggest laminar flow). Limestones occurring in both exotic-bearing sediments show different Upper Jurassic–lowest Cretaceous facies of a carbonate platform, which was involved in the source area of the Skole Basin, along with its basement. They can be interpreted as deposits of: 1) platform-margin reefs and a platform slope: a) partly silicified coral boundstone, b) microbial-coral boundstone, c) silicified sponge-microbial boundstone grading into peloidal-ooidal grainstone with bioclasts, and d) strongly silicified limestone with intraclasts and bioclasts; 2) deeper, platform slope to toe-of-slope area – bioclastic wackstone; 3) inner platform, including: a) partly silicified wackstone with peloids, small intraclasts and bioclasts, and b) microbial bindstone. Moreover, some exotic clasts are built of Albian–Cenomanian wackstone with abundant sponge spicules and planktonic foraminifers, which are interpreted as deeper shelf sediments. Taking into account the geometry of thrust sheets from the site of the exotic-bearing sediments to the edge of the Skole Nappe, along the most probable transportation path, including tectonic/erosional reduction and different variants of slope inclination, the distance of the mass flows attained at least 25–97 km from the shelf edge.

Key words: exotics, Štramberk-type limestone, debris flow, Carpathians.

INTRODUCTION

Exotic blocks or pebbles are a generally infrequent but characteristic component of flysch deposits. They are direct evidences of lithology in the source areas of these deposits. Such information is especially important when the source areas are tectonically or erosionally destructed, or deeply buried under an overthrust orogen, like in the Carpathians. Exotic blocks and pebbles from the Ropianka Formation (Campanian–Paleocene) in the Skole Nappe, mostly Štramberk-type limestones, gneisses or stone coals have been known for a long time (e.g., Uhlig, 1883), some of which are huge olistoliths (Wójcik, 1907). Their research is mostly focused on the lithological composition of the blocks and their age. Much less attention is paid to the type of deposits bearing them and their depositional processes, mostly because such deposits are poorly exposed (e.g., Wójcik, 1907; Bukowy and Geroch, 1957; Bromowicz, 1974; Kotlarczyk, 1978, 1988a). Therefore, their sedimentological and facies context is poorly understood.

In this paper, sedimentological features and facies context of exotic-bearing sediments from the Ropianka Formation (Campanian–Paleocene) of the Skole Nappe in the Wola Rafałowska section are presented. Moreover, exotic material of these deposits is characterized, and results of microscopic study of the exotic limestones are presented.

GEOLOGICAL SETTING

The Skole Nappe is the most external tectonic unit in the northern Carpathians, which contains Mesozoic deposits. Their sedimentation took place in the Skole Basin, started in the Early

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Received: July 30, 2015; accepted: November 2, 2015; first published online: December 3, 2015

Cretaceous and prolonged until the Miocene (Fig. 1C; Kotlarczyk, 1988a, b). The folded and internally thrust deposits of the Skole Basin were overthrust (as thrust sheets) upon the Miocene deposits of the unfolded Carpathian Foredeep and folded and thrust Miocene sediments of the Stebnik and Zgłobice units (Książkiewicz, 1972; Kotlarczyk, 1985, 1988a). Sedimentation in the Skole Nappe started in the Hauterivian with mostly dark mudstones (Bełwin Mudstone and Spas Shale), which pass into dark greenish shales with radiolarites (Dołhe Radiolarian Shale), representing the Cenomanian (Gucik, 1963). The Turonian changes in tectonic regime from extension to compression in the Skole Basin and its northern borderland initiated the flysch-type sedimentation of the Ropianka Formation. The Ropianka Formation, which contains the deposits studied, is up to 1.5 km thick and subdivided into the Cisowa Member (Turonian–Lower Campanian), Wiar Member (Lower Campanian–Lower Maastrichtian), Leszczyny Member (Lower Maastrichtian–Lower Paleocene) and Wola Korzeniecka Member (Paleocene) (Kotlarczyk, 1978). Each member starts with calcareous "flysch" facies and ends with "normal flysch" facies (Kotlarczyk, 1978, 1988a). The uppermost member suggests a deepening of the Skole Basin (Malata and Poprawa, 2006) at the transition to the overlying Variegated Shale whose sedimentation took place beneath the CCD (Rajchel, 1990; Leszczyński and Uchman, 1991; Bąk et al., 1997; Barwicz-Piskorz and Rajchel, 2012).

Chaotic sediments are a characteristic element of the Ropianka Formation. They occur already in the Cisowa Member in the "Fucoid Marl" (Bromowicz, 1974; Kotlarczyk, 1978). In the Wiar Member, conglomerates containing exotic pebbles were reported by Wdowiarz (1949), Bromowicz (1974), Kotlarczyk (1978) and Dżułyński et al. (1979). The Leszczyny Member con-

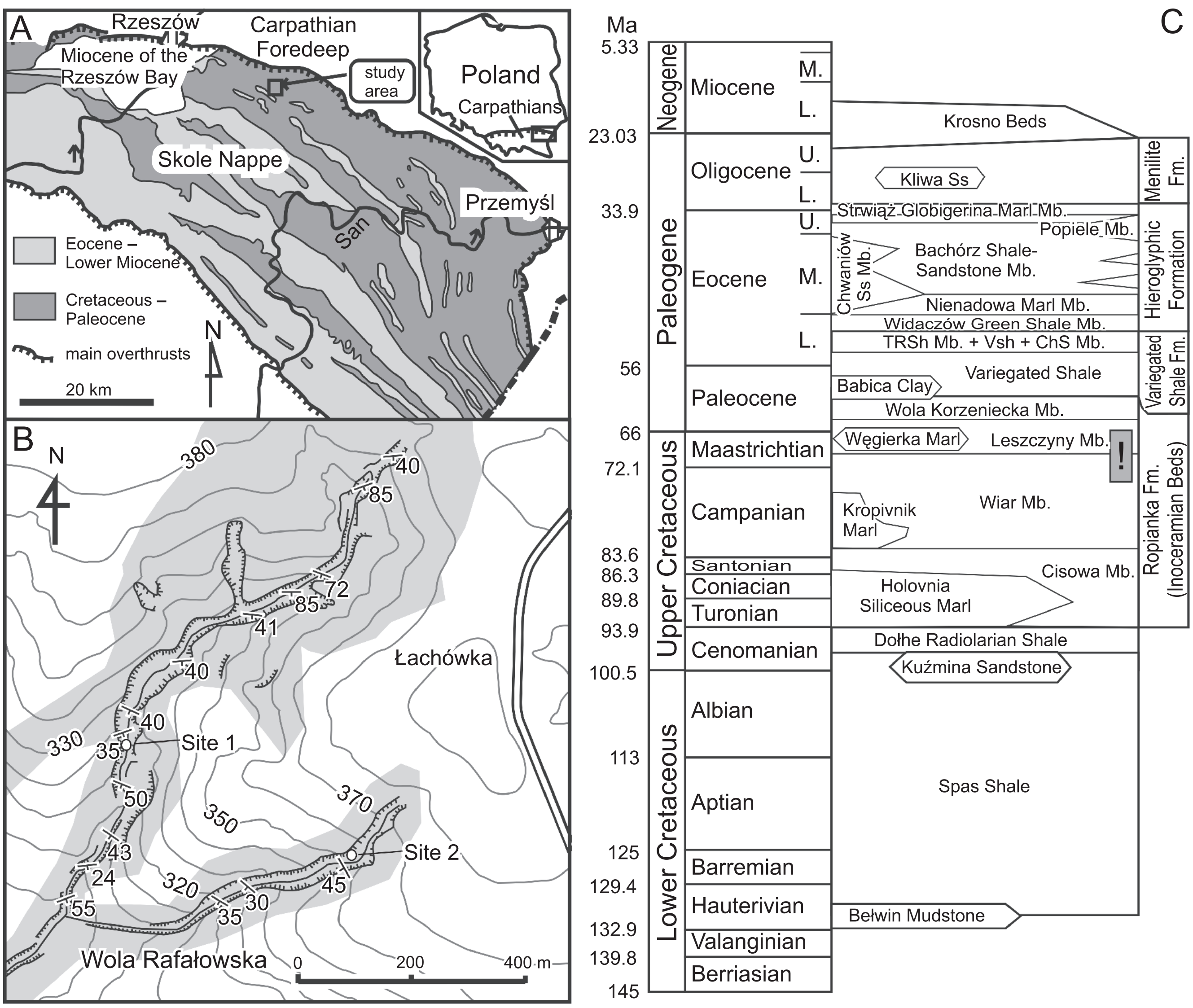

Fig. 1. Geographic and stratigraphic location of studied area

A – location map of the studied area in the Skole Nappe; based on Kotlarczyk (1988a) and modifications by Gasiński and Uchman (2009 and references therein); **B** – location of exotic material outcrops (site 1 and site 2) in Wola Rafałowska with some indicators of the orientation of beds as measured in the field; **C** – stratigraphic column of the Skole Nappe; based on Kotlarczyk (1988a), Rajchel (1990), Rajchel and Uchman (1998), Ślączka and Kaminski (1998), with further corrections based on further data by Gedl (1999) and Kotlarczyk et al. (2007); the investigated interval indicated by "!"; the time scale is after Gradstein et al. (2012); TRSh Mb. – Trójca Red Shale Member, VSh – Variegated Shale, ChS Mb. – Chmielnik Striped Sandstone Member tains the Baculites Marl (Węgierka Marl) developed as: 1) olistoliths of light coloured marls, 2) bedded marls, and 3) sandy debris flow sediments with blocks of limestones and marls (Burzewski, 1966; Kotlarczyk, 1978; Geroch et al., 1979). They are associated with conglomerates containing exotic material and large olistoliths of Tithonian limestones that occur south of Przemyśl (Wójcik, 1907; Bukowy and Geroch, 1957; Nowak, 1963; Kotlarczyk, 1988a). Maastrichtian pebble mudstones and conglomerates with exotic materials are distinguished as the Makówka Slump Debris (Kotlarczyk, 1978, 1988a; Dżułyński et al., 1979; Malata, 2001). Chaotic deposits are also noticed in other formations of the Skole Nappe. Similar, dark coloured sediments occur in the Paleocene Babica Clay (Kropaczek, 1917a, b; Bukowy, 1957a; Rajchel and Myszkowska, 1998; Szydło et al., 2014). Moreover, a 200 m thick olistostrome (Popiele Beds) occurs close to the Eocene-Oligocene boundary (Dżułyński and Kotlarczyk, 1965; Dżułyński et al., 1979; Kotlarczyk, 1988a; Szydło et al., 2014). Conglomerates with exotic material distinguished as the Siedliska Conglomerate are present within the Lower Oligocene succession (Kropaczek, 1917b; Pazdro, 1930; Kotlarczyk, 1985, 1988a). In the Lower Miocene, submarine slumps occur in the Leszczawka Diatomite (Dżułyński et al., 1979). The chaotic sediments are more common in the external than in the internal part of the Skole Nappe (Burzewski, 1966; Bromowicz, 1974; Kotlarczyk, 1978, 1988a), from the foreland side, which was their source area.

THE SECTION STUDIED

The studied section is located at Wola Rafałowska, 15 km SE of Rzeszów (Fig. 1A, B), at two sites. Sediments of the first site (site 1) crop out in a gorge of an unnamed stream, a tributary of the Chmielnik Stream (GPS coordinates: N 49°59'20.0''; E 22°11'0.93''; ±3 m). The second site (site 2) is located in a gorge of a similar unnamed stream to the SE from site 1 (GPS coordinates: N 49°59'11.7''; E 22°11'05.4''; ±5 m). The section belongs to the Husów Thrust Sheet, which is overthrust upon the Marginal Thrust Sheet (the frontal thrust sheet of the Skole Nappe) and is overthrust by the Hadle Kańczudzkie-Chmielnik Thrust Sheet (Wdowiarz, 1949). Judging from the map, the sites occupy approximate the same stratigraphic position.

The lower part of the Ropianka Formation section is represented by shale-sandstone flysch facies (Fig. 2). Thin and medium, rarely thick beds are composed of turbiditic, calcareous quartz-dominated sandstones in the lower part. Some beds display graded bedding in the lower part, starting from coarse sandstone, locally from conglomeratic grains (mainly quartz, stone coal, clasts of grey mudstones), to siltstone. Carbonised plant detritus is concentrated in parallel laminae in the upper part of the sandstones. Cross-bedding is much rarer. The lower bedding surface of the beds is sharp, locally with flute casts and bioturbation structures. The upper surface is diffusive with a gradual transition to grey or bluish-grey laminated sandy siltstones and grey to brownish mudstones. The rare thick beds (averagely 80 cm) from the lower part of the section are fine-grained, with indistinct graded bedding.

Up the section, layers of light bluish marls containing *Chondrites* and bioturbational structures occur frequently in sandstone-marl or siltstone/mudstone-marl couplets. The associated sandstones contain *Thalassinoides* and *Ophiomorpha*. Cross-bedding is more common in this part of the section, and wavy and convolute bedding occur not only in the sandstones, but also in siltstones and sandy mudstones.

In the middle and upper portion of the lower part of the section, a few layers of brown shales (variegated shale facies) occur, which suggest lower-energy hemipelagic sedimentation. It is possible that they belong to one of the variegated shales considered by Kotlarczyk (1978) as chronostratigraphic horizons. The lower part of the section is 330 m thick.

Up the section, sandstone beds are more frequent and coarser, with a smaller proportion of medium and coarse sand grains. The number of thin beds is decreasing, and the light bluish marls tend to disappear (Fig. 2). Carbonised plant detritus, often accompanied with stone coal clasts, occurs in 2–3 cm thick layers in some beds. In this part of the section, *Thalassinoides* and *Ophiomorpha* are still present. Beds of fine conglomerate are more frequent. In addition to limestone clasts (mostly Štramberk-type), they contain clasts of gneisses, sandstones and volcanic rocks. The conglomeratic material occurs also in the lower part of the graded sandstones beds. A thick conglomerate bed with exotic material (site 1) occurs in this (middle) part of the section, which is 250–300 m thick.

In the upper part of the section, beds of grey clayey, silty or sandy marls (Baculites Marl) start to crop out. Their amount increases up the section and they attain 100 m in total thickness. This unit, showing the same appearance and thickness, crops out in the stream to the SE. Therein, debris flow sediments containing exotic material (site 2) have been found at its base (Fig. 1B). Top part of the section (40 m) is composed of thin-bedded flysch dominated by siltstones and mudstones containing one layer of variegated shales. In this part of the section, bioturbational structures and carbonised plant detritus are much less frequent. Lithological features and dating by foraminifers suggest that the lower part and the lowest middle part of the section belong to the Wiar Member, while the upper part of the section belongs to the Leszczyny Member.

METHODS

During the fieldwork at site 1, orientation of the longer axis of 15 of pebbles was measured by using a geological compass. Conglomerates from site 1 and site 2 have been subjected to grain-size analysis. Data were collected from examination of 14 kg samples from site 1 and 10 kg samples from site 2. The samples were disintegrated after weighing. The rocks were washed with the use of a 0.05 mm sieve to remove clay fraction. After drying out, they were weighed again to estimate the loss of fine material. The remaining part of more cemented material was gently crushed in a mortar. Both samples were conducted through a column of sieves with diameters of 0.063, 0.1, 0.25, 0.5, 1, 2, 10, 25 and 40 mm. The material from each sieve was weighed and analysed under the *Nikon's SMZ1000* binocular microscope to estimate contents of each component. Independently of the grain-size analysis, petrographically different samples were collected in the field in order to identify composition of each conglomerate. The samples were cut and analysed macroscopically. Some of them were selected for thin sections, which were analysed under the *Nikon's Eclipse LV100 POL* polarizing microscope. Special attention was paid to limestone clasts which were subjected to microfacies and stratigraphic analyses based on microfossils.

EXOTIC-BEARING SEDIMENTS

The exotic-bearing sediments at site 1 occur in a thick, tectonically inclined bed dipping to the south-west (dip direction and dip angle: 210°/45°). Its base is covered by debris (Fig. 3A). Thickness of the missing, covered part is estimated to be

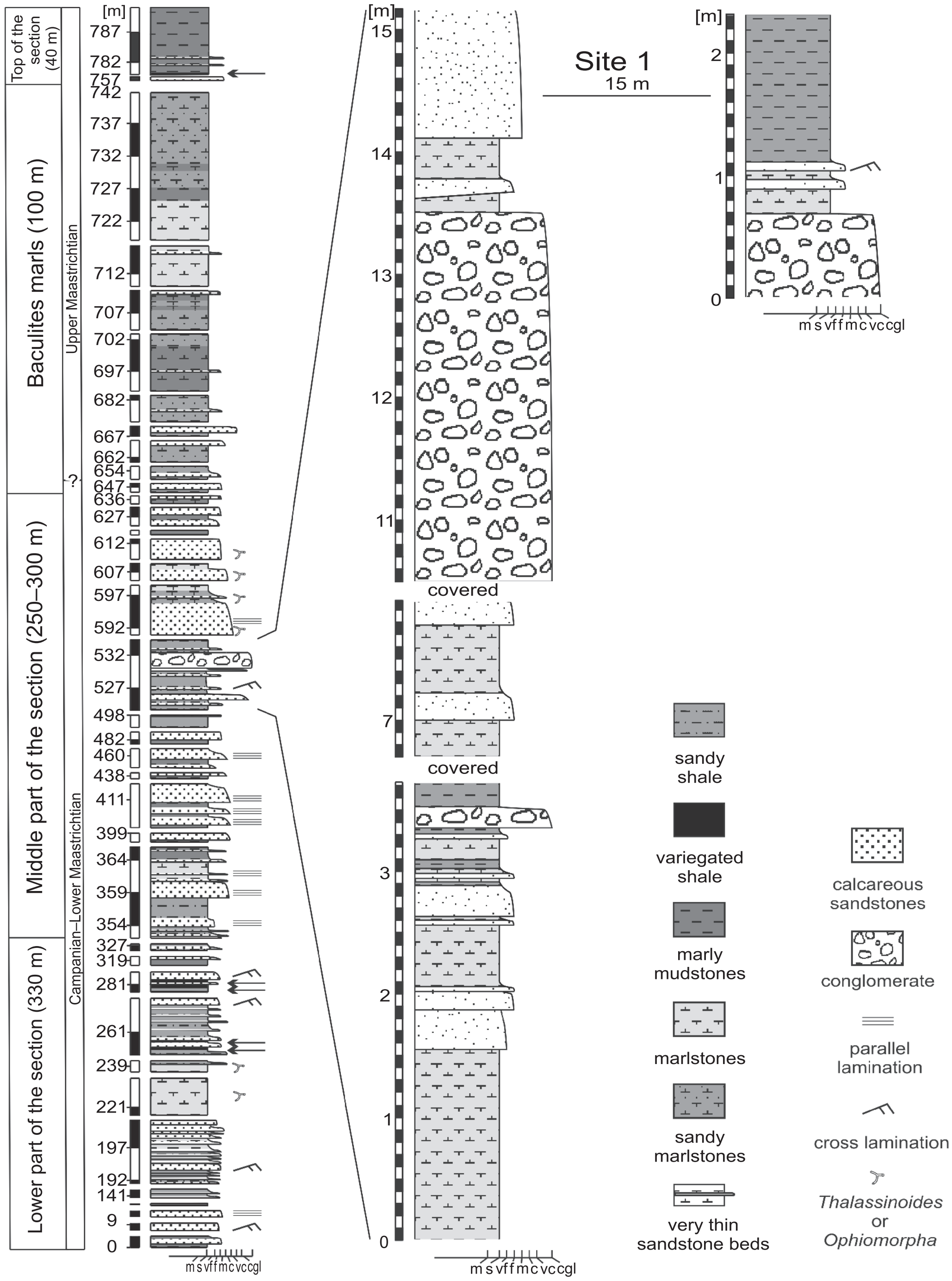

Fig. 2. Lithological columns of the Ropianka Formation in the Wola Rafałowska

2.5–3.0 m and is based on the field situation which includes dipping of the beds and position of the underlying sediment. The exposed part is 3 m thick and consists of polymictic conglomerate dominated by (in descending order) pebbles, cobbles and boulders of sandstones, gneisses, Štramberk-type limestones, volcanic rocks, pegmatites and ferruginous siltstones (Fig. 4). The grain-size class >40 mm is dominant (44.5% by weight), with the maximum clast size of 35 cm. The classes of 25–40 and 10–25 mm constitute 5.2 and 10.3% by weight, respectively, and are composed of the same lithologies as the class >40 mm. Some larger cobbles are crushed, probably during transportation (Fig. 3B). There is an important increase in grain-size in the class 2–10 mm (18.2% by weight; Fig. 5). These grains are built mostly of well-rounded, white, grey and black quartz (>90% by volume), and additionally of sandstones, gneisses, limestones and volcanic rocks. Grains of the class 0.063–2.0 mm are dominated by white, grey, black and pink quartz (>90% by volume). Roundness of quartz grains is decreasing with decreasing size of grains. Small amount of grains >0.5 mm is composed of glauconite and muscovite flakes. The amount of muscovite increases with decreasing grain size, maximally up to 3% (by volume) of grains >0.063 mm. The conglomerate is poorly sorted and matrix- to clast-supported. Poorly marked normal grading of clasts is visible in the exposed part. The orientation of the longest axes of clasts is mostly 210°. Roundness and degree of weathering of the conglomerate components are diverse and independent of lithology.

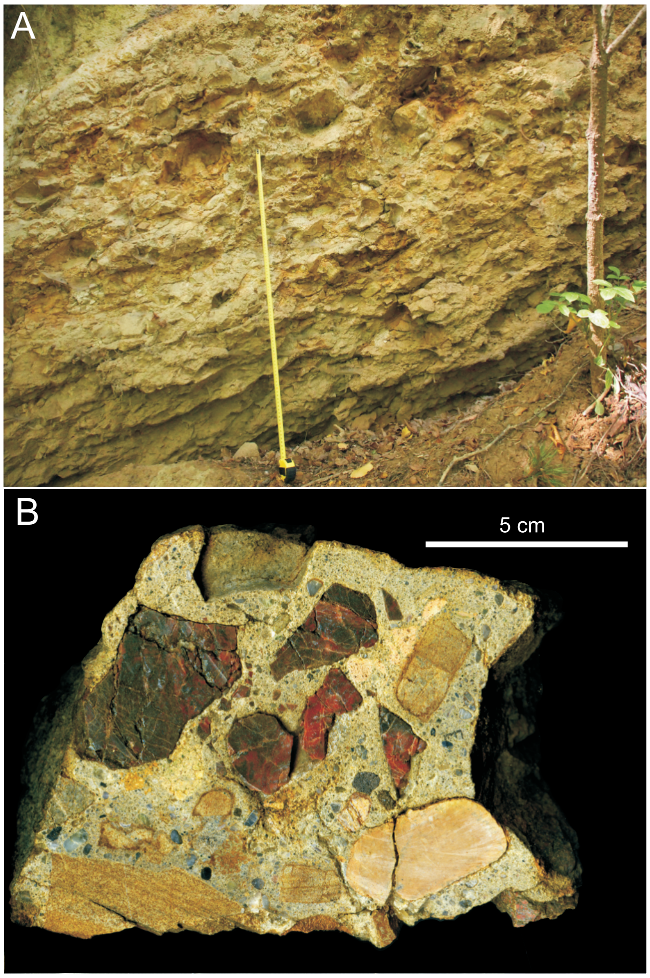

Fig. 3. Conglomerates from the Ropianka Formation at Wola Rafałowska, site 1

A – outcrop of conglomerates, site 1 (scale 1 m); **B** – sample of conglomerates from site 1

The matrix is cemented with calcareous matter. Above the conglomerate bed, a sandstone layer is sandwiched in light coloured marls, which altogether are covered by a thick sandstone bed. However, 15 m laterally away, the marls above the conglomerate contain one thinner sandstone bed in the middle part and one at the top. The latter is overlain by mudstones (Fig. 2). These lateral facies changes show that the top of the conglomerate was uneven, where elevations were a temporal obstacle for later turbidites that smoothed the topography by filling of depressions.

Sediments containing exotic material at site 2 are exposed on the right slope of the gorge of the stream. Because of the covered base and top of the bed, combined with the chaotic character of sediments, their dip and total thickness have not been determined. The thickness attains at least 3.0–3.5 m. The sediment consists of muddy matrix containing boulders of exotic rocks up to 30 cm in size. Clasts of volcanic rocks, marls, quartz gravel, black mudstones, schists, sandstones, gneisses, limestones, volcaniclastic rocks and conglomerates are floating within clay-rich matrix. The percentages of individual rock types in the section of site 2 is shown in Figure 4. Grains of size >40–10 mm constitute 30% by weight (Fig. 5). They are represented mostly by pebbles and cobbles of rocks mentioned above. Similarly to site 1, there is a significant increase in grains of the class 2–10 mm (14% by weight), but quartz is only one of the components along with schists, volcanic rocks, limestones, marls, stone coal and mudstones. Among grains of the class 1–2 mm, the amount of quartz rises significantly at the expense of the other components, such as some ferruginous siltstones known from site 1. Muscovite accounts for up to 2% of grains from the class 0.5–1.0 mm. In the grain class 0.25–0.5 mm, quartz is dominant and the above-listed components constitute 1–2% by volume. Finer grain-size classes are composed almost exclusively of quartz with a few percent of muscovite. Grains <0.063 mm constitute 40% of the rock by weight. All clasts are rounded and some have the shape of ventifact. Below the pebbly mudstone, there is a yellow-orange, fine-to medium-grained sandstone. It contains clasts of stone coal and grey mudstones. The sandy and muddy parts are sharply separated. It is not excluded that the sandstone is a partly exposed fragment of a huge boulder involved in the pebbly mudstone, or a fragment of a bed that is deformed by a pebbly mudstone mass flow.

LIMESTONE EXOTIC BLOCKS

The limestones from the exotic blocks at site 1 belong mostly to the Upper Jurassic–lowest Cretaceous Štramberk (Stramberg)-type limestones known from the Outer Carpathians (see: Discussion). Surfaces of some blocks are covered with imprints of gravels and sand grains. Most of them are more or less silicified. The silification obliterates primary fabrics, in-

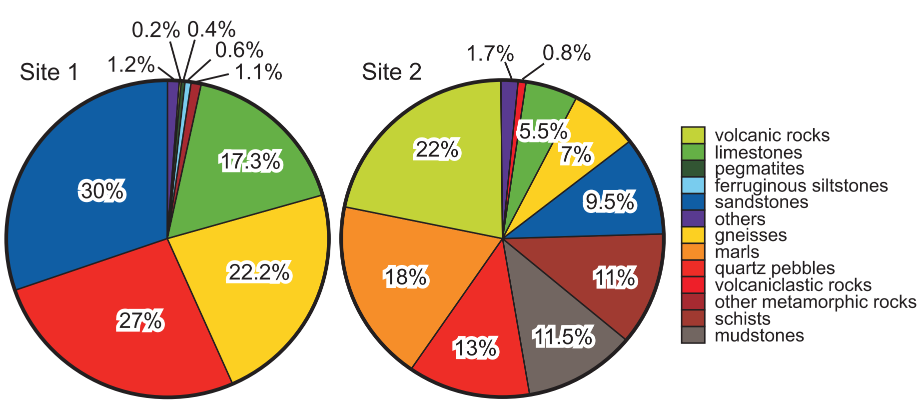

Fig. 4. Quantitative contribution of rock types in deposits from site 1 and site 2

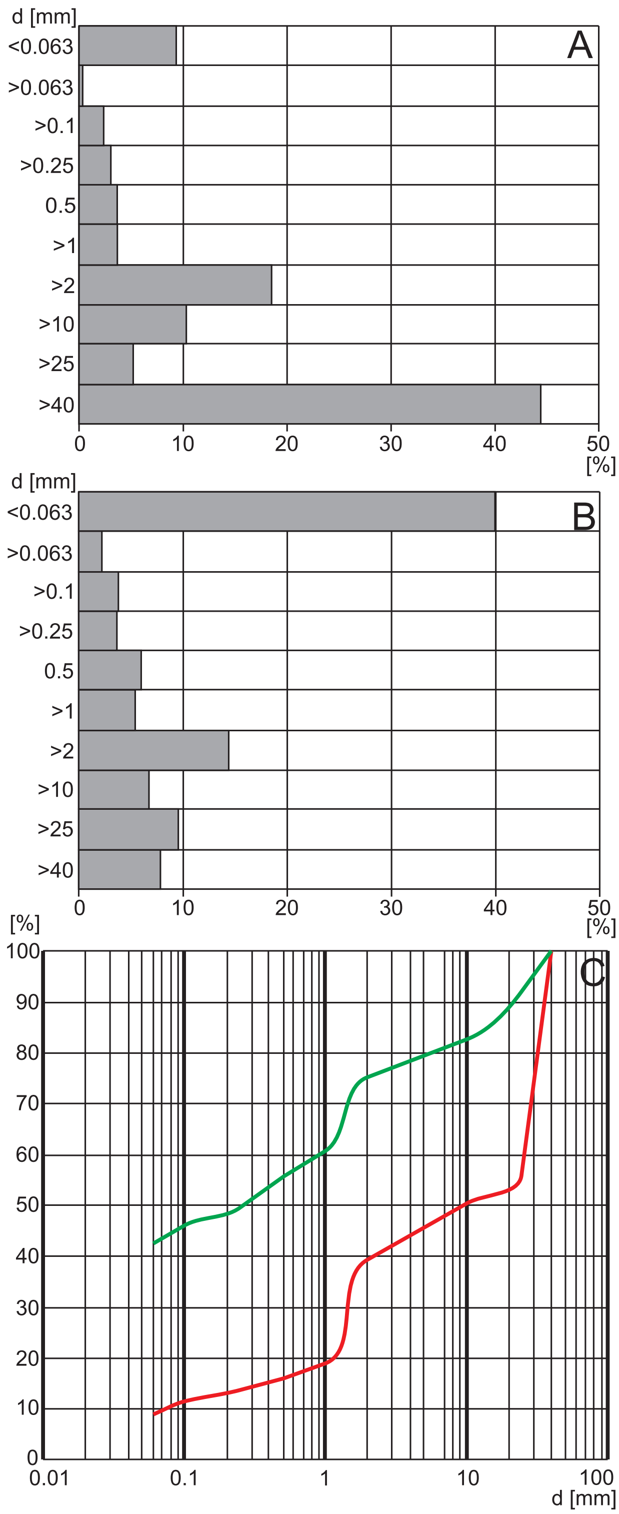

Fig. 5. Granulometry of deposits from site 1 and site 2

A – histogram from site 1; **B** – histogram from site 2; **C** – accumulation curves from site 1 (red) and site 2 (green)

cluding bioclasts. Therefore, identification of fossils and microfacies is difficult. Nevertheless, the microfacies point to several facies zones of an uppermost Jurassic–lowest Cretaceous carbonate platform, rarely to younger facies (Fig. 6).

Upper Jurassic–lowest Cretaceous limestones. Detailed environmental interpretation of the described samples of limestones is difficult, because generally the study of exotic pebbles only provides fragmentary information about the area of deposition, spatial relations between redeposited pebbles (and microfacies represented by them) are unknown, and the source area is not preserved. Moreover, microfacies analyses of the studied samples are hampered by the silicification.

The uppermost Jurassic–lowest Cretaceous limestones can be interpreted as:

1 – deposits of platform-margin reefs and a platform slope. They include peri-reefal components, and bioclasts typical of the inner platform, and they are represented by:

– partly silicified coral boundstone, in which space between corals is filled by peloidal-bioclastic material containing calcareous sponges, gastropod shells, few benthic foraminifers (including *Nautiloculina* sp.), *Crescentiella morronensis* (Crescenti), and *Globochaete alpina* Lombard (Fig. 7Q) – widely distributed, planktonic green alga, and tubes of the polychaetes: *Terebella lapilloides* Münster and ?*Mercierella dacica* Dragastan;

– microbial-coral boundstone, which, besides corals and microbial structures, contains several benthic foraminifers, such as *Paleogaudryina* sp., *Trocholina* sp. (Fig. 7H), and *Neotrocholina* div. sp., as well as *Crescentiella morronensis* (Crescenti), serpulid tubes, fragments of calcareous green algae (Dasycladales), and the problematic alga *Thaumathoporella* sp. Corals are encrusted by microfossil *Koskinobulina socialis* Cherchi et Schroeder;

– silicified sponge-microbial boundstone, with remnants of siliceous sponges, grading into peloidal-ooidal grainstone with bioclasts. Fossils of the grainstone are represented by calcareous sponges, ostracods, ?*Mercierella dacica* Dragastan, *Crescentiella morronensis* (Crescenti), calcareous dinoflagellates, foraminifers, including *Rumanolina* sp. (Fig. 7I), *Glomospirella* sp. (Fig. 7B), *Neotrocholina* sp. (Fig. 7C), and miliolids;

– strongly silicified limestone with intraclasts and bioclasts. Among the bioclasts, crinoid plates, fragments of corals, and calcareous green algae (Dasycladales) are found. Moreover, there are also *Globochaete alpina* Lombard, a single miliolid foraminifer (Fig. 7E), and *Crescentiella morronensis* (Crescenti). Some of intraclasts and bioclasts were transported from shallower parts of the platform;

2 – bioclastic wackstone can represent a slightly deeper, platform slope to toe-of-slope area. Fabric is not homogeneous; some poorly isolated lumps are noticeable, which can be related to burrowing or some slight reworking of partly lithified sediment. It contains sponge spicules, crinoid plates, echinoid spines, ostracod valves, and fragments of bivalve shells. Foraminifers are represented by the benthic genera of *Pseudomarssonella*, including *P.* cf. *dumortieri* (Schwager) (Fig. 7A), and fragments of other agglutinated foraminifers, as well as calcareous *Spirillina* sp., *Lenticulina* sp. (Fig. 7F), a single miliolid, and a single specimen of the family Epistominidae (Fig. 7D). Calcareous dinoflagellates and *Globochaete alpina* Lombard are also present;

3 – some exotics that most probably represent microfacies of the inner platform, include:

– partly silicified wackstone with peloids, small intraclasts and bioclasts. Benthic foraminifers are represented by miliolids, *Lenticulina* sp., *Neotrocholina* sp., and fragments of agglutinated foraminifers, including *Protomarssonella* sp. Moreover, *Crescentiella morronensis*

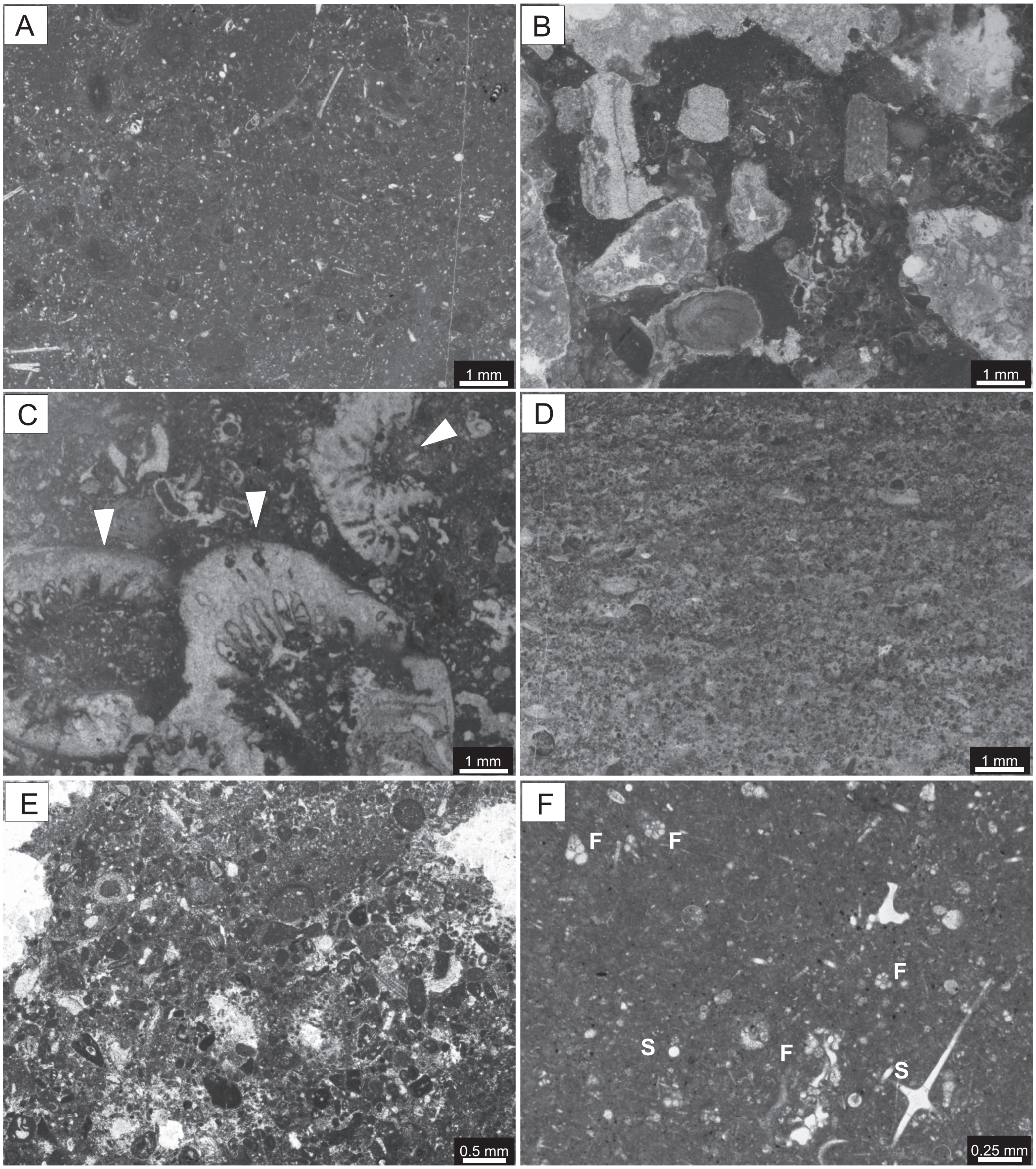

Fig. 6. Microfacies of exotic limestones from the Upper Jurassic–lowest Cretaceous (A–E) and "middle" Cretaceous (F)

A – bioclastic wackstone (thin section W. Raf.1); **B** – silicified limestone with intraclasts and bioclasts (thin section W. Raf.3); **C** – microbial-coral boundstone (corals – arrows; thin section 4B); **D** – microbial bindstone (thin section W. Raf.2); **E** – partly silicified wackstone with peloids, small intraclasts and bioclasts (thin section 6B); **F** – bioclastic wackstone with numerous sponge spicules (S) and planktonic foraminifers (F) (thin section 5B)

(Crescenti), rare echinoid spins, *Globochaete alpina* Lombard, a single calcareous dinoflagellate, and several poorly preserved calpionellids are present;

– microbial bindstone with several benthic foraminifers, such as *Reophax* sp., *Ophthalmidium* sp. (Fig. 7G), *Rumanolina* sp., and few nubecularid foraminifers.

More or less precise age of the described samples can be estimated based on calpionellids, calcareous dinoflagellates, and some other previously mentioned microfossils. Determination of foraminiferal species was mostly impossible, because of poor preservation caused by silicification. However, the foraminiferal genera, as well as other fossils, and microfacies fea-

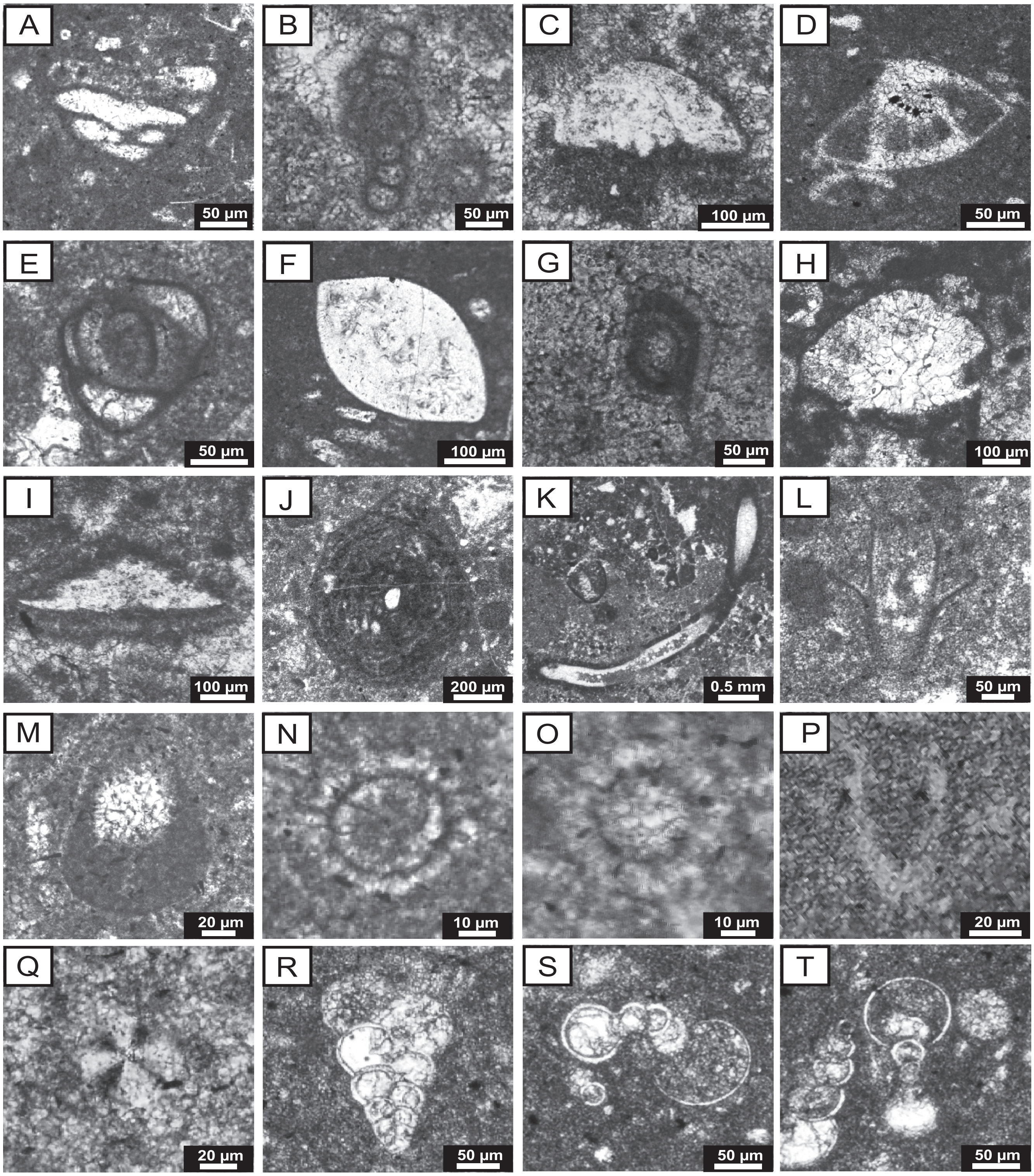

Fig. 7. Selected fossils of exotic limestones of the Upper Jurassic–lowest Cretaceous (A–Q) and foraminifers from the "middle" Cretaceous (R–T)

A–I – benthic foraminifers: A – *Pseudomarssonella* cf. *dumortieri* (Schwager) (thin section W. Raf.1); B – *Glomospirella* sp. (thin section 7B); C – *Neotrocholina* sp. (thin section 7B); D – foraminifer of the family Epistominidae (thin section W. Raf.1); E – miliolid foraminifer (thin section W. Raf.3); F – *Lenticulina* sp. (thin section W. Raf.1); G – *Ophthalmidium* sp. (thin section W. Raf.2); H – *Trocholina* sp. (thin section 4B); I – *Rumanolina* sp. (thin section 7B); **J** – cyanobacterial encrusting organism *Crescentiella morronensis* (Crescenti) (thin section 6B); **K, L** – polychaete worms: K – *Terebella lapilloides* Münster (thin section 3B); L – ?*Mercierella dacica* Dragastan (thin section 3B); **M–O** – calcareous dinoflagellates: M – *Crustocadosina semiradiata olzae* (Nowak) (thin section W. Raf.1); N – *Colomisphaera lapidosa* (Vogler) (thin section W. Raf.1); O – *Colomisphaera carpathica* (Borza) (thin section 6B); **P** – calpionella *Crassicollaria* sp. (thin section 6B); **Q** – algal zoospores *Globochaete alpina* Lombard (crossed polars; thin section 3B); **R–T** – planktonic foraminifers: R – *Heterohelix* cf. *reussi* (Cushman) (thin section 5B); S – *Hedbergella delrioensis* (Carsey) (thin section 5B); T – *Globigerinelloides bentonensis* (Morrow) (thin section 5B) tures of the limestones, are typical of the uppermost Jurassic and lowest Cretaceous (mostly Tithonian–Berriasian) limestone, mostly the Štramberk-type limestones, and they are remnants of carbonate platforms that surrounded (at least partly) the Silesian and Skole basins (see: Discussion).

Rare calpionellids occur only in one sample. They are poorly preserved; only *Crassicollaria* sp. (latest Tithonian–Early Berriasian; Fig. 7P) was determinable. Several species of calcareous dinoflagellates were determined: *Crustocadosina semiradiata olzae* (Nowak) (Fig. 7M) that ranges from the Early Berriasian (Nowak, 1966) to the Albian (Reháková, 2000), *Colomisphaera lapidosa* (Vogler) (Fig. 7N) which points to the Oxfordian–Berriasian (Olszewska, 2005), *Colomisphaera tenuis* (Nagy) form the Late Tithonian to Early Berriasian (Reháková, 2000), *Colomisphaera carpathica* (Borza) (Fig. 7O) ranging from the Late Oxfordian to the Berriasian (Olszewska, 2005), and *Crustocadosina semiradiata semiradiata* (Wanner) – known from the Oxfordian (e.g., Ivanova, 1994) to the Early Aptian (Reháková, 2000).

Also other microfossils typical of the Upper Jurassic–lowest Cretaceous limestones are present. *Crescentiella morronensis* (Crescenti) (Fig. 7J) is a common Middle Jurassic–Early Cretaceous microfossil, recently interpreted as nubecularid foraminifers incrusted by cyanobacteria (Senowbari-Daryan et al., 2008). ?*Mercierella dacica* Dragastan (Fig. 7L) ranges from the Kimmeridgian to the Berriasian in shallow environments of carbonate platforms (e.g., Mišík et al., 1999). *Terebella lapilloides* Münster (Fig. 7K) is typical especially of the Late Jurassic, mostly in deeper, lower energy environments, especially around mud mounds built of siliceous sponges, whereas in higher-energy conditions of coral reefs, it inhabited some protected voids (e.g., Flügel, 2010; Kaya and Altiner, 2014). *Koskinobulina socialis* Cherchi et Schroeder (Middle Jurassic–Early Cretaceous) is an incertae sedis microfossil, which was an important component of microencruster framework of the Upper Jurassic and Lower Cretaceous platform-margin reefs (e.g., Hoffmann et al., 2008; Schlagintweit and Gawlick, 2008).

Other limestones. Besides the Upper Jurassic–lowest Cretaceous, other limestones are rare. They are limited to wackstone with abundant sponge spicules and planktonic foraminifers (one sample; Fig. 6F). The latter belongs to the genera *Heterohelix* (Fig. 7R), *Hedbergella* (Fig. 7S), and *Globigerinelloides* (Fig. 7T), suggesting the Albian–Cenomanian age. This facies can be interpreted as a deeper shelf deposit.

At site 2, rounded clasts of white limestone are present, up to 3.5 x 4.5 x 3 cm in size. They include: 1) wackestone with peloids and unidentified, strongly recrystallised bioclasts, whose surface is covered with imprints of gravel and coarse sand grains, 2) mudstone with smooth surfaces and rare circular tunnels, whose diameter ranges from 0.5 to 1.5 mm; the longest fragment of the tunnel is up to 7 mm long. Proportion of the limestones is up to several percent and it decreases with decreasing grain size. The limestones at site 2 are similar to the platform slope and inner platform facies mentioned above.

Marls and black mudstones. At site 2, small clasts of marls and black mudstones are present. They constitute about a few percent of the rocks. Poorly rounded white to light grey marl pebbles with orange and brown coatings up to 5 x 4 x 10 cm in size, without signs of grain imprints, contain foraminifers, including *Lenticulina*, *Cibicidoides*, *Heterohelix*, *Globigerinelloides*, and globotruncanids, which suggest the Campanian–Maastrichtian age. They were probably redeposited from the shelf. Moreover, pebbles of grey marls are present, which easily disintegrate into cubes. The marls contain foraminifers of *Heterohelix*, *Globigerinelloides* and *Nothia* and small clasts of stone coal and ferruginous siltstones.

Other exotic components at site 2 are clasts of dark grey to almost black mudstones. They contain foraminifers similar to the mentioned grey marls.

Quartz gravel. Quartz occurs at both sites as very well rounded gravel grains, mostly 0.5–10 mm, exceptionally up to 30 mm in diameter. The quartz is white, grey, yellow, pink, red or black with mat surfaces, mono- or polycrystalline. It is mostly equant and bladed with rare oblate and prolate shape. Quartz gravel dominates grains >2 mm at site 1 while at site 2 it occurs only occasionally.

Sandstones and mudstones. Clasts of a few types of sandstone occur at both sites. The most abundant is a calcareous quartz arenite, which is yellow-orange passing into bronze on a weathered surface, composed of fine-grained quartz with addition of muscovite and limonite, and cut by calcite veins. The sandstones are mostly parallel laminated and/or display small scale, low angle cross beddings. Higher degree of diagenesis of the sandstone at site 2 can be marked by darker colours and at least partial obliteration of sedimentary structure. The sandstone clasts often preserve bedding surfaces, which makes them blocky in shape but rounded on the edges. Clasts from site 1 are up to 5 x 15 x 12 cm in size.

At site 2, four types of sandstones and one type of mudstone were noticed:

– the same calcareous quartz arenite as at site 1. At site 2, the sizes are smaller and are up to 8 x 5.5 x 6 cm. This type is most abundant at site 2;
– grey-greenish sandstone composed of quartz with addition of muscovite and red feldspar. This is also quartz arenite with strong dovetail of grains and green colour probably derived from chlorites. Clasts are up to 6.5 x 4 x 2 cm in size and are well-rounded;
– dark grey-green, very fine-grained, with addition of quartz grains up to 1 mm. Moreover, it contains many black unidentified minerals. Clasts are well-rounded and up to 4 x 1 x 3 cm in size;
– quartz wacke built of red rounded quartz, 1–2 mm in size. Silty matrix is cemented with calcareous matter. Its clast is 3 x 2.5 x 1 cm in size;
– clasts of grey mudstones with black bioturbational structures. The clasts are cubic in shape and poorly rounded, 1.5 x 2 x 2.5 cm in size.

Ferruginous siltstones. At site 1, there are orange-yellow limonite-siderite siltstones. Their clasts are up to 4.5 x 9 cm in size. Clasts are angular with sharp edges. They account up to a few percent of all exotic material. Similar material is present at site 2, but it occurs only as an addition to the grain-size classes below 2 mm.

Stone coal. Stone coal occurs only at site 2. It is poorly rounded, shiny, with cubic size up to 1.5 cm. The stone coal is fresh and its amount is around 1–2%. At site 1, several metres beneath the conglomerate bed with exotic material, there is another conglomerate bed cropping out. It contains mostly quartz and addition of cubic, shiny and mat stone coal, which clasts are up to 4 cm in size. In the Ropianka Formation, similar clasts of stone coal are dated as Carboniferous (Bukowy, 1957b; Kotlarczyk and Śliwowa, 1963).

Gneisses and pegmatites. Clasts of gneisses from site 1 are abundant and blocky in shape with slightly rounded edges. Smaller clasts display usually more sharp edges (Fig. 3B). The gneisses are fresh to strongly weathered. They form the largest clasts in conglomerate (up to 35 x 15 x 8 cm in size) at site 1. The gneisses are much smaller and rare at site 2. They are dark grey-red and consist of mono- and polycrystalline quartz, sericitised feldspar, muscovite, chlorite and zircon. Some of the gneisses show eye-like structures (augens). Different-looking gneisses have uniform composition that suggests one protolith that has undergone different processes in time.

At site 1, some clasts consist of coarse crystals of grey and white quartz with small inclusions of red feldspar. Clasts are poorly rounded and are up to 9 x 6 x 4 cm in size. Their structure suggests a vein (pegmatite) origin.

Volcanic rocks. At both outcrops there are well-rounded clasts of volcanic rocks represented by yellow, pink, red, purple, grey and grey-greenish porphyry with white and pink phenocrysts of feldspar, amphibole and quartz, and occasionally chlorite. The conglomerate matrix from site 1 contains fine clasts of volcanic rocks, which show phenocrysts of quartz and opal under microscope. The clasts are variably weathered and >40 mm and up to 11 x 2.5 x 5 cm in size. These volcanic rocks can be classified as rhyolites, trachytes and andesites. One clast from site 2 displays a shape of ventifact.

Another volcanic porphyry rock occurs only at site 2. It is almost black, locally green, with pink phenocrysts. Moreover, a chloritised basaltoid occurs at site 2, with very fine crystals of yellow-white feldspar within the brown aphanite groundmass. It contains many irregular pores filled with secondary minerals, mostly calcite.

At site 1, volcanic clasts constitute up to a few percent of all material, but at site 2, they are among the most abundant rock types.

Volcaniclastic rocks. At site 2, there is a single, well-rounded clast of a conglomerate showing features of volcaniclastic rock. The conglomerate is composed of dark grey clasts, locally irregular white feldspar crystals, black irregular amphibole crystals, welded green and yellow-white minerals, and sharp-edge clasts of red rocks similar to gneisses from site 1. All these components are floating in a pink-violet aphanite groundmass.

Schists. Metamorphic rocks occur at site 2 and are represented by well-rounded quartz mica schists with chlorite, whose clasts are up to 6.5 x 2 x 4.5 cm in size. The second type of the metamorphic rock consists of muscovite and steel-grey, slightly greenish chlorite. This rock is a mica schist. The clasts are up to 2.5 x 4 x 1 cm in size. Both rock types show a strong foliation associated with a directional orientation of mica flakes. Similar but smaller clasts occur in the conglomerate at site 2.

Problematic lithologies. There are also some problematic lithologies that are left unrecognized. At site 1, there are black-grey to orange clasts with abundant muscovite and some dark minerals within a very fine groundmass. It seems like they are very weathered igneous rocks. Their average size is 3 x 3.5 x 3 cm. A rounded clast of a green, easily crumbling, very fine-grained rock with addition of muscovite is present at site 1. This material looks like a very weathered igneous rock or tuffite.

DISCUSSION

THE EXOTIC-BEARING DEPOSITS

The low content of cohesive material (<10%) in the conglomerate from site 1 (Fig. 5) does not contradict the possibility of debris flow, because even this amount may highly increase the mobility of flow (Rodine and Johnson, 1976; Lowe, 1982). Poorly sorted sediment mixed with water can be easily transported (Lowe, 1976). Experimental data show that an increase in water content in low cohesive flow results in a further travel distance (Marr et al., 2001). Low cohesion resulting from the small content of mud causes easier transportation of coarse material and leads probably to a poorly marked gradation of grains (Kuenen, 1965; Ilstad et al., 2004). Talling et al. (2012) show that four types of gradation could exist in debrites, including:

- grading of outsized clasts;
- grading of the uppermost part due to reworking by overlying flow;
- local size segregation due to dewatering during *in situ* consolidation;
- thin basal layers with inverse grading due to kinetic sieving.

The crushed clasts probably resulted from collisions, and additionally support the evidence of low viscosity and matrix strength of the flow (cf. Hoedemaker, 1973). Mulder and Alexander (2001) point to a huge influence of particle interactions in flows with grain concentration above 25%. Crushing of the clasts during tectonic transportation of the thrust is rather impossible because this process should involve all type of clasts equally and should be localized in zones of tectonic deformations. Almost exclusive content of exotic blocks only in the conglomerate may be explained by the lack of erosion due to hydroplaning (Harbitz et al., 2003), but this stands in opposition with the postulated low cohesion (cf. Mohrig et al., 1998). An explanation of this contradiction can come from the possible rip-up clasts that may occur at the base of the bed (not observed due to covering). It is not excluded that the semi-lithified clasts may be disintegrated during flow and incorporated into the matrix (Haughton et al., 2003), however, any evidence of that have not been noticed. Talling et al. (2012) proposed a model where the boundary between cohesive and non-cohesive debris flows are at 20% of cohesive material. According to this model, the conglomerate from site 1 may be referred to as clean sand debrite.

Walker (1975) distinguished four facies of conglomerates in turbiditic depositional environments. The conglomerate from site 1 can be classified as facies 2 (graded conglomerate). However, an inverse grading in the lowest part of the bed (not accessible) is not completely excluded; if it is present the conglomerate may be ascribed to facies 3. Due to exposure conditions, there is no certainty if the clast orientation of 210° (parallel to top of the bed) at site 1 coincides with the direction of transportation. However, Bromowicz (1974) showed that the bulk of sediments in the NW part of the Skole Nappe was derived from a source area situated to the north and north-west. Probably, the axes are perpendicular to the flow direction, and this orientation allows rolling of clasts (Walker, 1975; Posementier and Walker, 2006). Many authors suggest that gradation in conglomerates is not caused by debris flow but by a high-density turbiditic flow (Walker, 1976; Lowe 1982; Talling et al., 2012). In high-density turbiditic flow, concentrated material is transported near the bottom and is driven by a more dilute turbulent flow from above (Postma et al., 1988). Lowe (1976, 1982) suggested four coexisting mechanisms of support in such a type of flow: the fluid turbulence, hindered settling, matrix buoyant lift and dispersive pressure. It is not clear if the base of the conglomerate at site 1 shows any sign of R1 (coarse gravel showing traction structures) or R2 (inversely graded gravel layer) divisions by Lowe (1982). Lack of a sandy part at the top of the gravely turbiditic beds may point to a bypass of remaining sandy turbiditic flow after deposition of R3 (normally graded gravel layer) and possible R1–R2 divisions (Lowe, 1982).

One of the most visible differences between deposits of site 1 and site 2 is the content of mud, which greatly affect physical features, such as viscosity, yield strength, size of matrix-supported clasts and mixing rates with ambient fluid (Iverson et al., 2010). The pebbly mudstone from site 2 shows many features typical of the cohesive debris flow, foremost the chaotic distribution of clasts and their freely floating in matrix (matrix-supported type), poor sorting (Lowe, 1982; Shanmugam and Moiola, 1995; Shanmugam et al., 1996) and the occurrence of fragile clasts of marls and shales (Enos, 1977). The limited exposition of this bed prevents closer observations of possible features, such as irregular top or inverse grading, which are typical of debris flows (Shanmugam et al., 1996). The very high content of grains <0.063 mm and freely floating clasts point to a strong cohesion, which probably prevent dilution of the head of the flow and origination of the turbidity current at the top (Ilstad et al., 2004; Talling et al., 2012). The pebbly mudstone studied contains exotic material as well as intraformational material, which suggests bottom erosion despite appropriate composition for hydroplaning (Harbitz et al., 2003). However, both processes can be explained by erosion during the first phase of flow, and then hydroplaning due to an increase in density and velocity, or by accumulation of the shales and marls in the source area and their further incorporation in the pebbly mudstone flow. The occurrence of foraminifers from bathymetrically different zones in deposits of site 2 indicates that shallow and deep material was mixed during transportation, similarly to the situation in the Babica Clay (Bukowy, 1957a). Gravel flows of different origin can sink in and mix with unlithified muds during flow (Crowell, 1957). Pebbly mudstone from site 2 represents high- to moderate-strength cohesive debrite DM-2, according to the classification by Talling et al. (2012).

The literature offers many reports about conglomerates in the Skole Nappe. Only some of them are similar to these from sites 1 and 2. The conglomerate at site 1 is only partly similar to sediments from the vicinity of Przemyśl (Wójcik, 1907; Bukowy and Geroch, 1957; Dżułyński et al., 1979), where the cited authors described conglomerates containing huge cobbles, boulders and olistoliths freely floating in the muddy or marly matrix. The clasts are almost exclusively limestones accompanied by a small amount of magmatic and metamorphic rocks. The Makówka Slump Beds are featured by a little amount of limestones, and magmatic and metamorphic rocks, but by abundant clasts of mudstones, marls and sandstones (Dżułyński et al., 1979; Kotlarczyk, 1988a; Malata, 2001). Below the Babica Clay, there are conglomerates similar to these at site 1 (Bukowy, 1957a), but the composition of their clasts is limited to quartz, different types of shales, stone coals, limestones and porphyry. Clasts in the conglomerate below the Babica Clay are rounded, graded and oriented parallel to the top of beds like at site 1. Lithologies of crystalline exotic pebbles similar to that from site 1 were mentioned by Skulich (1986). Skulich (1986) reported similar conglomerates, but with abundant pegmatites, from "Paleocene beds with exotics", however, it is unclear what lithostratigraphic units these deposits represent (?Babica Clay). Conglomerates with exotic material similar in composition to site 1 are rare in the Skole Nappe SE to Rzeszów (Wdowiarz, 1949; Bromowicz, 1974). Typical conglomerate of the Ropianka Formation in this area contains quartz, schists, stone coal, and locally light coloured limestones.Their clasts do not exceed several centimetres in size (Wdowiarz, 1949).

The pebbly mudstone from site 2 shows the greatest similarity to that in the Babica Clay (Bukowy, 1957a). In both cases, exotic material is mixed with ripped-up clasts that freely float together in mud-rich matrix containing a small amount of sand. Clasts in the Babica Clay reach up to a few metres, while these from site 2 are no larger than 30 cm. However, it is not clear if the thick sandstone in the lower part of site 2 represents a part of a large block within the debris blow or a layer. Bukowy (1957a) recognized directional orientation of clasts that show feature of transport from the north. In the pebbly mudstone from site 2, such feature is unnoticed. Some clasts in the Babica Clay, such as dolomites or dark Paleozoic limestones are absent at site 2. This may be a result of progress in erosion of the source area during the Paleocene. At site 2, almost all clasts are rounded, where the roundness of clasts in the Babica Clay is diverse even for the clasts of the same lithology (Bukowy, 1957a). In the Babica Clay the ventifact shape is present in clasts of different lithologies (Bukowy, 1957a; Szymakowska, 1961), whereas at site 2 only one clast of this shape was found. The occurrence of volcaniclastic conglomerates in the studied sediments is a new feature in the Ropianka Formation. Such lithologies have been found only in the exotic material from the Spas Shale (Veřovice Shale of Skulich, 1986) and Paleocene units (Skulich, 1986).

ESTIMATION OF TRANSPORT DISTANCE

In this work the minimal distance of the flow represented by the studied conglomerates is determined. The distance from the place of deposition to the toe-of-slope was estimated by stretching of the two thrust sheet in the area between the sites and the northern margin of the Skole Nappe, i.e. the Marginal Thrust Sheet and the Husów Thrust Sheet, including estimation of their eroded parts (Fig. 8A). The Husów Thrust Sheet was stretched only partly (up to the studied sites) due to the uncertainty in the continuation of exotic-bearing deposits farther to the south. The modern continental slopes are inclined at an angle ranging from 1 to 45° (Drake and Burk, 1974; Davies, 1977), but the prevailing values of 1–25° are used in the model proposed (Fig. 8B) because more confined data about the slope inclinationin the study area are missing. The water depth was estimated on the basis of the occurrence of background calcareous shales and marls in the Wola Rafałowska section, interpreted as deposited above the calcite compensation depth and keeping in mind that the marginal part of the Skole Basin should be shallower than the central part. The calcite compensation depth was estimated to be 4–4.5 km for the Upper Campanian–Maastrichtian part of the Ropianka Formation on the basis of comparison to the Atlantic during the same time interval (Uchman et al., 2006). Malata and Poprawa (2006) suggested that the depth of the Skole Basin had been no greater than 3 km. The model includes estimation of the distance between the source area of deposits of the exotic material and the hypothetic shelf edge at 200 m of water depth and with a constant slope gradient within the range of 1° (Fig. 8B2) and 25° (Fig. 8B1), and the alternative depths of the basin from 2 to 4 km. The authors are aware that the slope gradient does not need to be constant, the water depth was only approximately determined, and the amount of rocks eroded after formation of thrust sheets is only hypothetical. Nevertheless, the results can provide some estimation of the scale of processes in the Skole Basin.

The obtained result ranges between 22 and 97 km, depending on the slope gradient (Fig. 8B). A steeper slope and hence the smaller distance (ca. 25 km) is more probable, because the width of the Skole Basin is estimated at 140 km (Gągała et al., 2012) and the localities studied represent the northern, marginal part of the basin.

The sediments studied should be able to flow down a surface sloping at 2°, or even below 1° (Lewis, 1971; Talling et al., 2012). Gee et al. (1999 and references therein) recognized debris flow of 5–25 m thick and 25 km wide, which travelled 700 km, so the estimated distance of flow for the studied sediments is not exceptional in terms of the distance. It is possible that these flows can continue farther to the south.

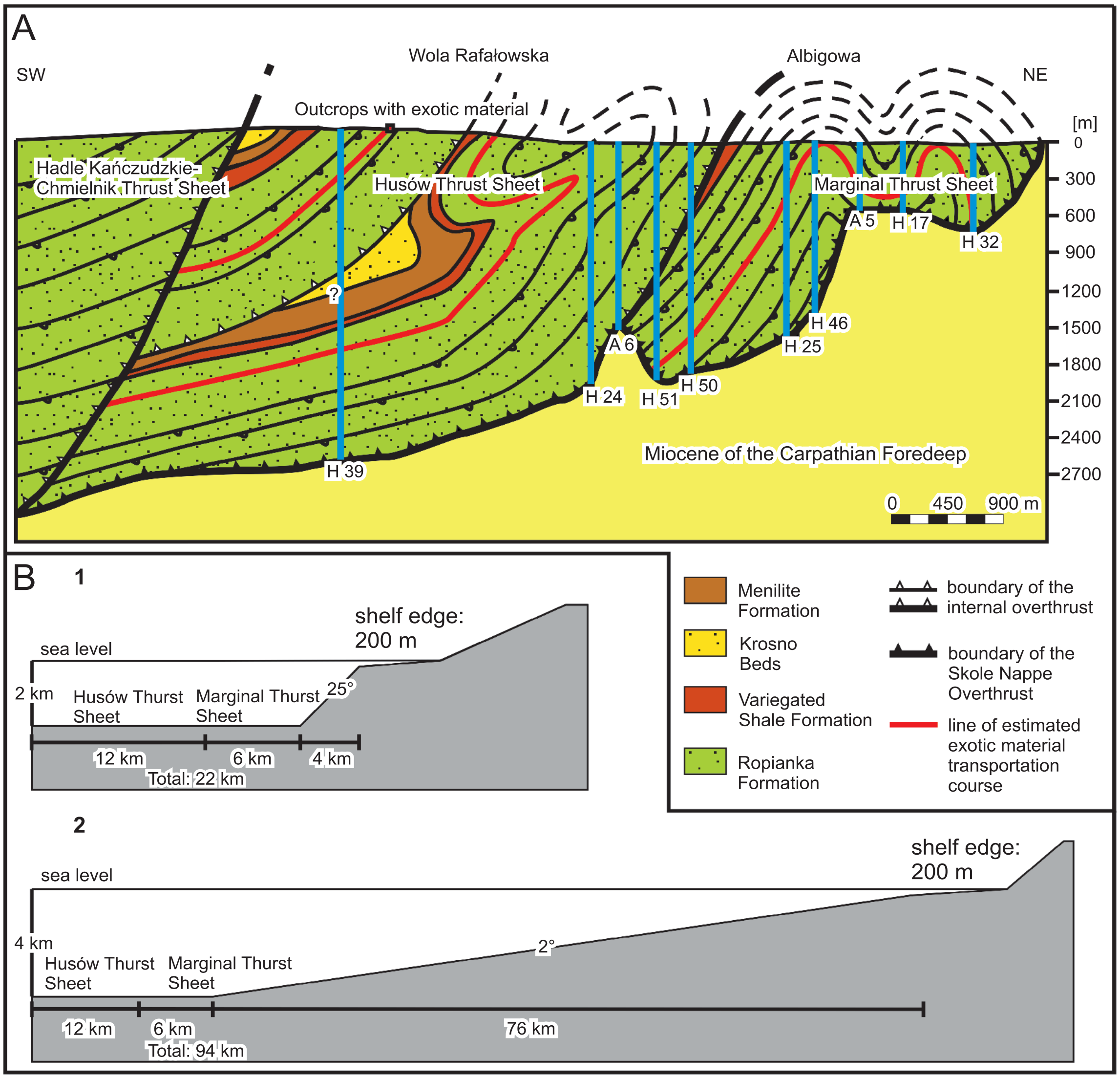

Fig. 8. Estimation of transportation distance for conglomerates from site 1

A – tectonic cross-section of the northern part of the Skole Nappe in the study area; based on data from Wdowiarz (1949), Gucik et al. (1980), Woiński (1994), Dusza et al. (2004), boreholes data from: otworywiertnicze.pgi.gov.pl, including Husów 17 (Fik, 1976), Husów 24 (Rak, 1977), Husów 25 (Rak, 1979), Husów 32 (Rak, 1978), Husów 39 (Garbarcik et al., 1977), 46 (Rak, 1981), Husów 50 (Rak, 1981), Husów 51 (Rak, 1980), Albigowa 5 (Kwolek, 1963), and Albigowa 6 (author unknown, inw. 95467 NAG, Warszawa); the tectonic structures were stretched along the red line; **B** – minimal and maximal values of the transportation distance obtained with different parameters of inclination of slope and basin depth; model of the minimal (1) and maximal (2) value of the transportation distance

EXOTIC MATERIAL AND ITS PROVENANCE

The exotic limestones represent mostly facies typical of the uppermost Jurassic–lowest Cretaceous carbonate platform and platform slope deposits. They accumulated north of the Tethyan deep-water basins that developed along the southern margin of the European shelf during the latest Jurassic (e.g., Birkenmajer, 1986; Săndulescu, 1988) and on the intra-basinal ridges, foremost on the Silesian Ridge (e.g., Krobicki et al., 2004 and reference therein). Tectonic destruction and erosion of the platforms caused redeposition of the limestone exotic material into the basins to form debrites containing olistoliths, boulders and pebbles. Larger bodies of limestones are known from several klippes in the vicinity of Štramberk (Moravia, Czech Republic) (see e.g., Houša, 1975, 1990; Eliáš and Eliášová, 1984), where they are referred to as a fore reef, reef edge, inner reef flat, and back reef zones of diverse reef complex that developed along the Baška Elevation (Eliášová, 1981; Eliáš and Eliášová, 1984) within the submarine Subsilesian Ridge on the northern margin of the Silesian Basin. In the vicinity of Štramberk, the limestones are dated to the Tithonian–Early Berriasian (e.g., Houša, 1990) but their sedimentation in other areas could prolong until the Valanginian (Soták, 1989; Soták and Mišík, 1993; Ivanova and Kołodziej, 2010; Kołodziej, 2015). Subduction of the intra-basinal ridges and slopes of the basins caused that the sedimentation areas of the exotic material are not accessible for direct studies. Only the exotic material within the deposits filling the Carpathian basins, in their more axial parts, is their indirect evidence (e.g., Książkiewicz, 1962; Cieszkowski et al., 2005).

The term "Štramberk-type limestones" is especially applied to reef facies, but also generally to sediments of carbonate platforms (see e.g., Salamon and Trzęsiok, 2015). These exotic limestones are distributed in different-scale debrites within deep-marine flysch clastic series from the Early Cretaceous to Oligocene in the Silesian, Subsilesian and Skole nappes (e.g., Andrusov, 1959; Nowak, 1963; Morycowa, 1964, 2008; Eliáš, 1970; Burtan et al., 1984; Soták, 1987; Golonka et al., 2003; Ivanova and Kołodziej, 2010; Kowal-Kasprzyk, 2014; Kołodziej, 2015). The term "Štramberk-type limestones" is also used for rocks known from the South Carpathians in Romania and from the Balkan Mountains in Serbia (e.g., Săsăran and Bucur, 2001; Tchoumatchenco et al., 2006), and for carbonate exotics from Turkey (Masse et al., 2015). In the Polish Outer Carpathians, the Štramberk-type limestones are the commonest exotic limestones, however, calcareous rocks of the Paleozoic, Triassic, Oxfordian–Kimmeridgian, as well as younger Cretaceous and Paleogene are also noticed (e.g., Burtan et al., 1984; Cieszkowski et al., 2005).

Stone coals are abundant in flysch and associated sediments in the Polish Flysch Carpathians from the Lower Cretaceous to the Middle Miocene (Bukowy, 1957b; Kotlarczyk and Śliwowa, 1963). Size of the coal clasts is variable and reaches even a few metres (Bukowy, 1957b). Marginal character of the Skole Nappe resulted in the largest amount of stone coal in its sedimentary series. The stone coal derives from the Carboniferous coal-bearing sediments on the northern margin of Carpathian basins during the Cretaceous and Paleogene (Bukowy, 1957b; Kotlarczyk and Śliwowa, 1963). Dating of spores and pollen proves the Westphalian age of the stone coal (Kotlarczyk and Śliwowa, 1963). An assemblage of spores and pollen from stone coal intermediate between the Upper Silesian Coal Basin and the Lublin Coal Basin indicates a transitional zone that is today situated under the overthrust belt of the Carpathian nappes (Bukowy, 1957b; Kotlarczyk and Śliwowa, 1963). It is not clear if the transitional zone had connections with the Upper Silesian Coal Basin or the Lublin Coal Basin. The Western Carpathian basins had diverse source areas where coal contains spores typical of the Upper Silesian Coal Basin. Erosion of land north of the Skole Basin is marked in a gradual decrease of the size of stone coal and its roundness up the section of the Skole Nappe (Kotlarczyk and Śliwowa, 1963). The stone coal should not be misleading for lignite created from organic matter brought to the Skole Basin and carbonised during the Oligocene (Kotlarczyk, 1979).

The crystalline rocks, represented by gneisses, come from the basement of the sedimentary rocks. Wdowiarz (1949) reported that they are represented mostly by granites and gneisses. Bromowicz (1974, 1986 and references therein) recognized also metaquartzites among fine grains. In the Bircza area, south-east of the study area, porphyritic andesite and dacite clasts have been noticed (Nowak, 1963).

PALAEOGEOGRAPHIC CONTEXT

In the Ropianka Formation of the Skole Nappe, in the areas located south-east of Rzeszów, the sediments were transported from the northwestern margin of the Skole Basin called the Northern Cordillera or Marginal Cordillera (e.g., Książkiewicz, 1962; Bromowicz, 1974, 1986 and references therein). The frequency of exotic pebbles suggests that the source area occupied by the crystalline rocks was smaller than the area covered by sedimentary rocks (Bromowicz, 1974, 1986). Although sedimentary clasts dominate in the Skole Basin (Bromowicz, 1974, 1986), including the study area, large accumulations of igneous and metamorphic rocks are present locally. Tourmaline from the Ropianka Formation sandstones, derived from igneous and medium-grade metamorphic rocks, and its bimodal roundness suggest a first-cycle and polycyclic origin (Salata, 2014). Changes in the source area due to erosion have consequences in the content of heavy minerals in flysch sediments (Salata and Uchman, 2013). The mineral ratios change from the Campanian–Maastrichtian to the Oligocene and point to a transition from an immature passive margin (Ropianka Formation) to a mature passive margin (Menilite Formation). The Skole Nappe shows a decreasing number and decreasing diversity of exotic rocks from the Cretaceous to the Oligocene (Kotlarczyk and Śliwowa, 1963; Ślączka and Unrug, 1966; Kotlarczyk, 1976). Independently, during sedimentation lasting 70 Ma, many factors, such as climatic and relative sea level changes or tectonic activity, affected the source area and the basin.

CONCLUSIONS

The graded conglomerate (site 1) and the pebbly mudstone (site 2) show different structures and textures, which may reflect differences in sedimentary processes. The pebbly mudstone is a sediment showing features that derived from debris flows (high amount of matrix-supported, poorly sorted cohesive material, lack of grain-size gradation and traction structures that suggest a laminar flow), whereas the graded conglomerate shows features of both debris flows (poorly sorted, matrix- to clast-supported, high amount of cobble to boulder fraction) and high-density turbiditic currents (indistinct normal gradation, small amount of cohesive material, crushed clasts that suggest an interaction between grains during transportation and at least partly turbulence during flow). Nevertheless, the lack of full exposure makes some uncertainty in interpretation of its sedimentary processes.

Transport of both sediment types took place from the slope of the Northern Marginal Cordillera whose upper part was located to the NE at the distance of 22–97 km.

The presence of the uppermost Jurassic and lowest Cretaceous limestones representing diverse microfacies typical of carbonate platforms and slopes of platforms (mostly so-called Štramberk-type limestones) among the exotic material in the Ropianka Formation, confirms that, during the Late Jurassic and the earliest Cretaceous, shallow-water carbonate sedimentation was widely distributed along the margins of the proto-Silesian Basin, which embraced the later differentiated Skole Basin.

Lithological content and contribution of exotics are different in both sites. Site 1 contains a large amount of sandstones, quartz gravels, gneisses and limestones with a small addition of other metamorphic rocks, ferruginous siltstones, pegmatites and volcanic rocks. Site 2 contains (in decreasing order) volcanic rocks, marls, quartz gravels, mudstones, schists, sandstones, gneisses, limestones, volcaniclastic rocks and stone coal. These differences may suggest two independent sources and different processes of transportation (with possible and without intrabasinal erosion). Nevertheless, without data on transport direction of both sediment types this is only a speculation. A comparison with other exotic-bearing rocks (conglomerates near Przemyśl, the Babica Clay, the Makówka Slump Debris) of similar age shows that the petrographic constitution of the Northern Marginal Cordillera located to the NE was complex and varied from W to E.

Acknowledgements. The Jagiellonian University (DS funds) financially supported the research. The identification of lithology of the exotics was assisted by M. Paszkowski (Kraków) and D. Salata (Kraków). A.M. Gasiński (Kraków) helped in determination of some foraminifers. J. Janočko (Košice), J. Soták (Bratislava) and J. Rajchel (Kraków) provided helpful and critical reviews.

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