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Geological setting and lithological inventory of the Czarna Woda conglomerates (Magura Nappe, Polish Outer Carpathians)

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ABSTRACT:

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During the late Oligocene to early Miocene the residual Magura Basin was located along the front of the Pieniny Klippen Belt (PKB). This basin was supplied with clastic material derived from a south-eastern direction. In the Małe (Little) Pieniny Mts. in Poland, the late Oligocene/ early Miocene Kremna Fm. of the Magura Nappe (Krynica subunit) occurs both in front of the PKB as well as in the tectonic windows within the PKB. Lenses of exotic conglomerates in the Kremna Fm. contain frequent clasts of Mesozoic limestones (e.g. limestones with "filaments" microfacies and Urgonian limestones) and Eocene shallow-water limestones. Fragments of crystalline and volcanic rocks occur subordinately. The provenance of these exotic rocks could be probably connected with Eocene exhumation and erosion of the SE part of the Dacia and Tisza Mega-Units.

Key words: Exotic rocks; Source areas; Magura Basin; Stratigraphy; Paleogeography.

INTRODUCTION

The Western Outer Carpathian (WOC) sedimentary basins were supplied with clastic material derived from external and internal source areas, traditionally referred to as "cordilleras" (Książkiewicz 1960, 1965). These source areas supplied the Carpathian flysch basins with sedimentary and crystalline "exotic" pebbles. This material was transported into the basin by submarine gravity flows (Książkiewicz 1960, 1965, 1968). In the WOC sedimentary basin system, the most important internal source area is regarded as the "Silesian Cordillera". This source was composed of the Silesian, Andrychów and Marmarosh continental ridges (Książkiewicz 1965, 1968; Unrug 1968; Sikora 1971; Oszczypko and Żytko 1987; Picha *et al.* 2006; Golonka *et al.* 2000; Oszczypko 1992, 2006; Oszczypko *et al.* 2005a). The Silesian Ridge separated the northern – Silesian Basin from the southern – Magura Basin (Unrug 1968). The Silesian Ridge supplied the Silesian, Dukla and Magura (Siary subunit) basins, with clastic material containing Variscan plutonic and metamorphic rocks (Poprawa *et al.* 2004). During the Campanian, inversion-related uplift of the Silesian Ridge affected also the northern part of the Magura Basin, the event accompanied by the onset of flysch deposition. By contrast, the beginning of the flysch deposition, along the southern margin of the Magura Basin (Peri-Klippen Zone) took place later during the Late Cretaceous and Paleocene (Książkiewicz 1977). The Paleogene deposits of this part of the Magura Basin (Krynica Zone) contain several horizons with exotic conglomerates of unclear provenance (e.g. Wieser 1970; Oszczypko 1975; Mišík *et al.* 1991a, b; Oszczypko *et al.* 2006; Olszewska and Oszczypko 2010; Salata and Oszczypko 2010; Oszczypko *et al.* 2016).

The aim of this paper is to present a lithological inventory of the Czarna Woda conglomerates belonging to the youngest deposits of the Magura Succession – the Kremna Fm. (late Oligocene /early Miocene). The focus is on provenance analysis of the carbonate clasts and their comparison to the Jarmuta conglomerates (Cretaceous–?Paleocene) of the PKB in the Małe Pieniny Mts.

PREVIOUS STUDIES

In the southern part of the Magura Nappe (Text-fig. 1), the Paleogene "exotic" conglomerates have been known for many years (Jaksa-Bykowski 1925; Mochnacka and Węcławik 1967; Wieser 1970; Oszczypko 1975; Birkenmajer *et al.* 1987; Mišík *et al.* 1991a, b; Oszczypko *et al.* 2006; Olszewska and Oszczypko 2010; Oszczypko *et al.* 2016). The first detailed description of exotic clasts from the Polish sector of the Magura Unit (Krynica Zone) was given by Mochnacka and Węcławik (1967), who studied both crystalline and sedimentary pebbles from Tylicz. A few years later, Oszczypko (1975) found granitoids, gneisses, phyllites and quartzites (38.3–87.0%) with a relatively small amount of Triassic to Paleocene carbonates (3.8–38.1%) and basic volcanic rocks in the Eocene deposits of the Beskid Sądecki Range (Krynica Zone).

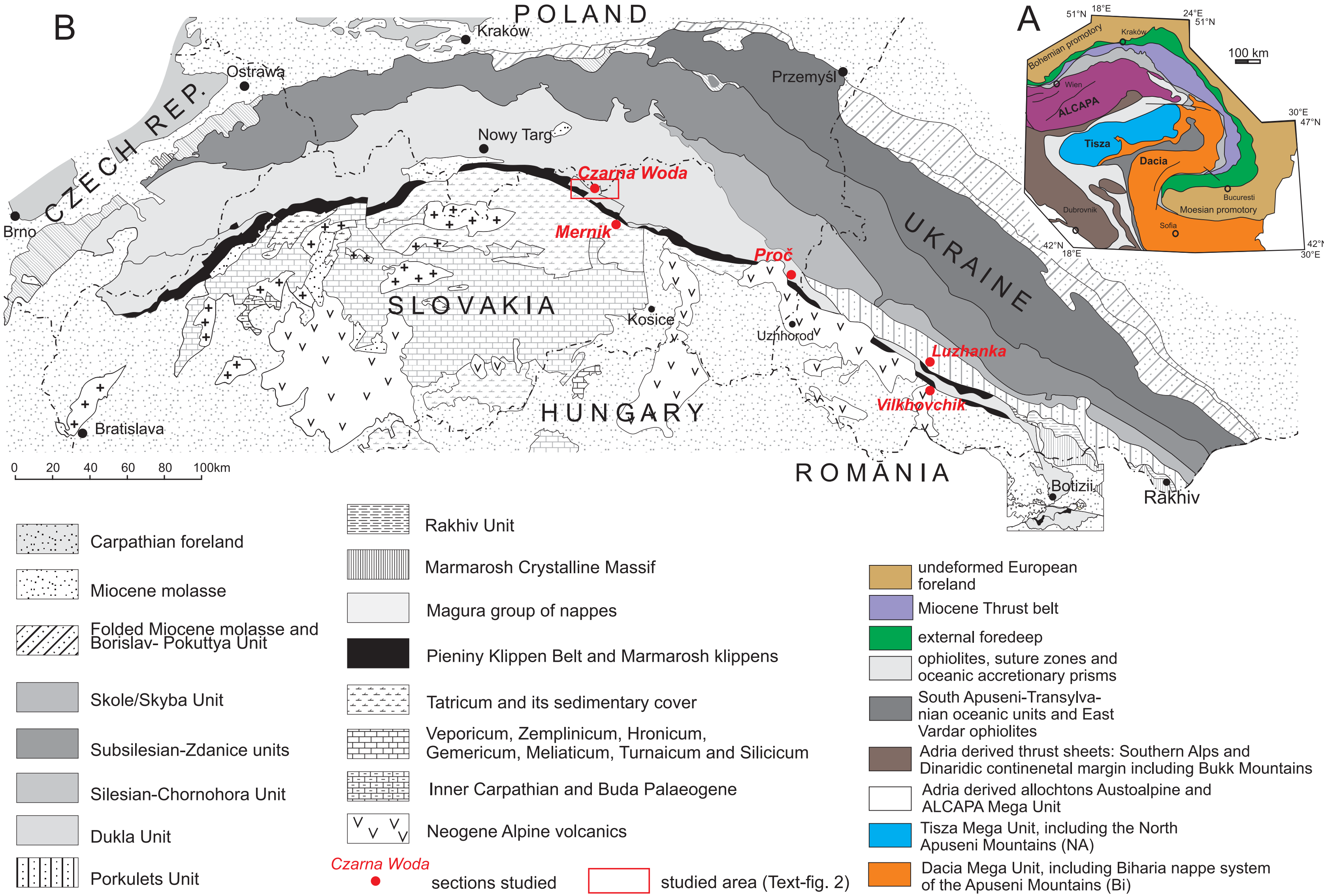
Mišík *et al.* (1991a, b) analysed in detail both the Proč and Strihovce conglomerates, located along the northern periphery of the PKB in eastern Slovakia (Text-fig. 1B). These conglomerates differ both in petrographic composition as well as in their origin. The Proč conglomerates are composed of carbonates (76.12%), clastic rocks (7.7%), silicates (4.93%), volcanites (7.8%), granitoids (1.25%) and metamorphic rocks as well as vein quartz (0.86%). The granitoids of the Proč conglomerates were dated by Boyko *et al.* (1974) as Early Cretaceous (Berriasian–Cenomanian; 140–99 Ma). In contrast, the Strihovce conglomerates (Mišík *et al.* 1991b) are dominated by sedimentary rocks, mainly clastics (55.5%) that are associated with metamorphic (34.5%) and volcanic rocks (10.1%). Among the sedimentary clasts of the Strihovce conglomerates, carbonate clasts are subordinate (10.1%; Mišík *et al.* 1991b). This type of conglomerate was also described by Oszczypko *et al.* (2006) from several sections of the Magura Sandstone Fm. (Krynica Zone of the Magura Unit in Poland), which contained: 41–48% of magmatic and metamorphic rocks, 26–46% of vein quartz 9–16% of Mesozoic carbonates and 4–10% of flysch sandstones. In the studied material, the share of effusive rocks, does not exceed a few percent (Wieser 1970).

Deposits similar to the Proč conglomerates are known also from Trans-Carpathian Ukraine (Text-fig. 1B) as the Vilkhovchyk (Luzhanka) conglomerates (Text-fig. 1B) (Kruglov and Smirnov 1967; Gofstein and Dabagyan 1967; Černov 1973; Kruglov 2006). These conglomerates, recognized both along the northern and southern edges of the PKB, are dominated by sedimentary rocks (75.5%), mainly Lower/middle Cretaceous limestones, that are accompanied by magmatic (8.6%) and metamorphic (6.95%) rocks. The radiometric ages of these rocks (Boyko *et al.* 1974) were determined at 136–90 Ma (granites and granodiorites) and 110–67 Ma (diorites and quartz porphyries-rhyolites). Certain similarity to the above-described conglomerates is also revealed by the Merník conglomerates (late Eocene to early Oligocene) from SE Slovakia (Soták *et al.* 1991). These debris-flow conglomerates (Text-fig. 1B) were documented at the PKB/Central Carpathians Paleogene boundary.

In Poland, similarity to the Proč conglomerates is shown by pebbles and clasts from the Tylicz conglomerates (upper Eocene/Oligocene, Olszewska and Oszczypko 2010). These conglomerates have been recognized at the boundary between the Bystrica and Krynica zones of the Magura Nappe, directly above the Mniszek correlative horizon (variegated shales, middle–?late Eocene). They contain fragments of crystalline rocks and very frequent clasts of Mesozoic to Paleogene deep- and shallow-water limestones (up 44%). The isotopic ages of "exotic" pebbles from this section indicate a Variscan age for the plutonic and metamorphic rocks (Oszczypko *et al.* 2016).

The provenance of the Proč conglomerates and their equivalents can be related to Eocene/Oligocene exhumation of the SE termination of the Magura Basin (e.g. "Neopieninic cordillera" of the East Carpathians (Mišík *et al.* 1991a): the Dacia and Tisza Mega-Units (Text-fig. 1). In contrast, the provenance of the Strihovce conglomerates was associated with the "South Magura cordillera" (Mišík *et al.* 1991b).

Indeed, the recent study of detrital garnets, tourmalines and zircons from the Eocene Strihovce Fm. (Krynica subunit, eastern Slovakia) by Bónová *et al.* (2018) supported by paleotransport measurements (Bónová *et al.* 2018) suggests that during the Eocene, the crystalline complexes of the Tisza Mega-Unit could have been the lateral (southeast) source area



Text-fig. 1. A – Tectonic sketch-map of the Alpine–Carpathian–Pannonian area (after Schmid *et al.* 2008). B –Tectonic sketch-map of the Western Carpathians and adjacent Ukrainian Carpathians with location of the study area (based on Oszczypko *et al.* 2015).

for the Strihovce type conglomerates, in the Krynica sector of the Magura Basin.

THE PROBLEM OF THE JARMUTA CONGLOMERATES

According to Książkiewicz (1968), the exotic conglomerates of the PKB occur at three levels: as the upper Santonian–Campanian Upohlav conglomerates, the Maastrichtian–Paleocene Jarmuta conglomerates, and the lower Eocene Złatne conglomerates. The Jarmuta Fm. is the uppermost lithostratigraphic unit of the Grajcarek Succession (Birkenmajer 1979). In the latter (Text-fig. 2), the Jarmuta sedimentary breccia is wedged between the Grajcarek Unit (N) and the Niedzica scales of the PKB in the S (Birkenmajer 1979). This breccia, c. 2 m thick, is composed of fine sandstones, quartzites, limestones and marls. Kutyba (1986) described the Jarmuta conglomerates from the Czarna Woda Stream, located c. 800 m north of the PKB (Text-fig. 2). The petrographic composition of these conglomerates was estimated by Birkenmajer *et al.* (1987) to contain 27% of cherty limestones (Tithonian /Neocomian), 25% of spotty limestones and marls (Upper Jurassic ?), 13% of muscovite sandstones, 7% of granitoids, gneiss and metamorphic slates, 5% of dolostones (Triassic), 5% of greenish marls (Upper Cretaceous), 4% of white and rose limestones (Middle Jurassic), 4% of keratophyres and micrograniti es, 3% of green and bluish limestones, 3% of white and grey quartzites, 2% of cherty limestones and radiolarites and 2% of brown sandstones. In the matrix, middle Paleocene calcareous nannoplankton (NP4) and early Paleocene planktonic foraminifera (*Globigerina triloculinoides* Plummer) were recognized (Birkenmajer *et al.* 1987).

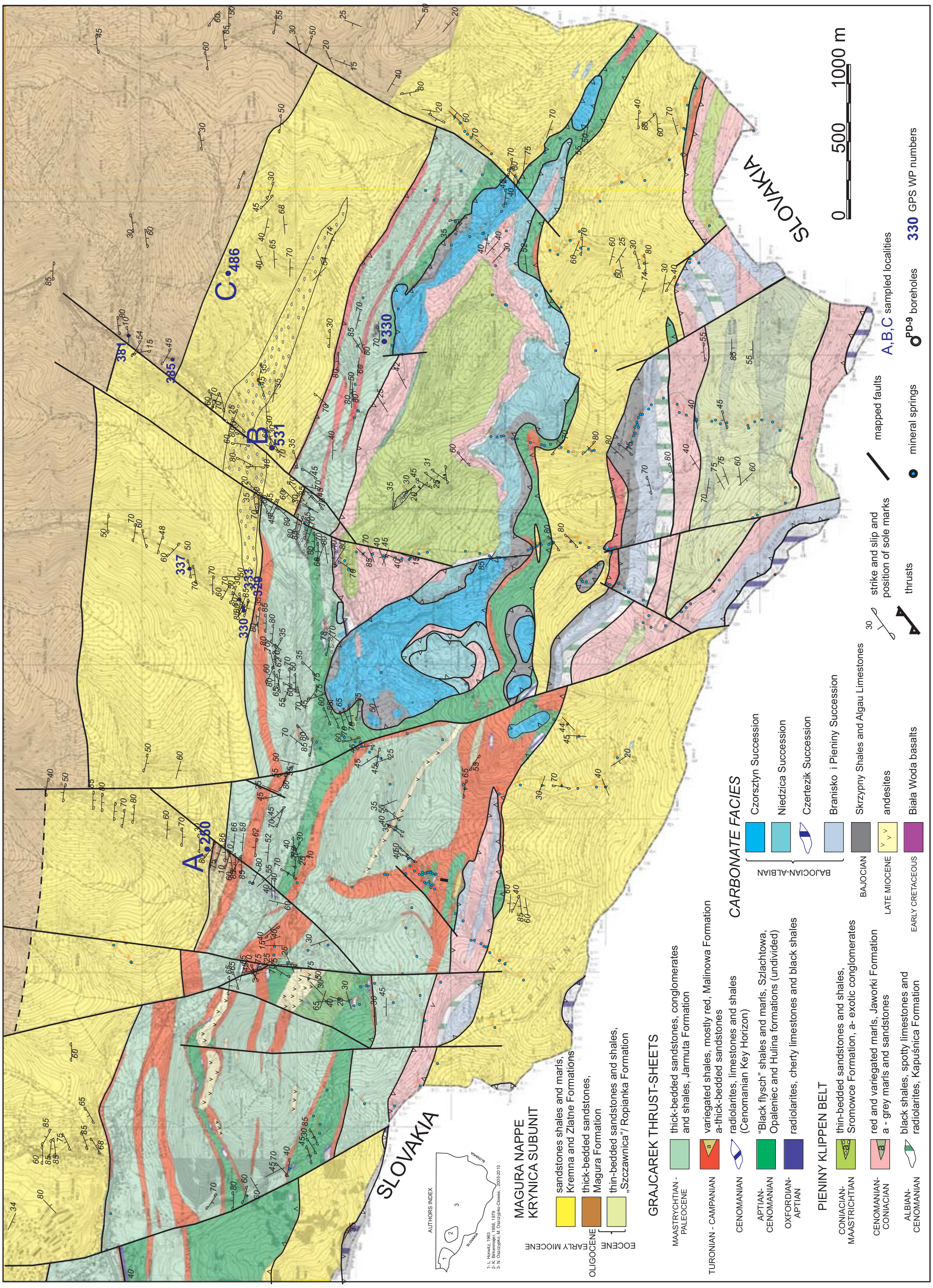
However, the Jarmuta conglomerates display another petrographic composition in the locality on the right slope of the Biała Woda Valley, close to a big block of basalt (Text-figs 2, 3, 4A). These conglomerates (Text-fig. 4B) consist of volcanites, mainly pyroclastics (59%), limestones and dolomites (15%), sedimentary clastic rocks (11%), sedimentary and hydrothermal silicate rocks (10%) and metamorphic rocks (3%) (Birkenmajer and Wieser 1990). The radiometric age of the basaltic body was estimated at 140 ±8 Ma (Early Cretaceous; Text-fig. 4A) by Birkenmajer and Pécskay (2000). Birkenmajer and Wieser (1990) postulated that both the Biała Woda basaltic body and the exotic pebbles of the Jarmuta conglomerates were formed in the course of Late Jurassic through Cretaceous subduction of the PKB basin under the Andrusov Ridge (see also Birkenmajer 1988).

In the Małe Pieniny Mts., the Jarmuta Fm., up to 300 m thick (Text-figs 2, 3), is developed as sedimentary breccia, olistoliths, exotic conglomerates as well as thick-bedded turbiditic sandstones (Oszczypko *et al.* 2012; Oszczypko and Oszczypko-Clowes 2014, 2017). Most of the material of the Jarmuta conglomerates is of local origin (derived from the PKB). Similarly in the lower part of the Czarna Woda Stream (Text-fig. 2), the Jarmuta Fm. contains debris flow para-conglomerates with big clasts of red shales of the Malinowa Fm. (Turonian–Campanian) and small blocks of the Jurassic/Lower Cretaceous pelitic limestones derived from the PKB (Oszczypko *et al.* 2012; Oszczypko and Oszczypko-Clowes 2014).

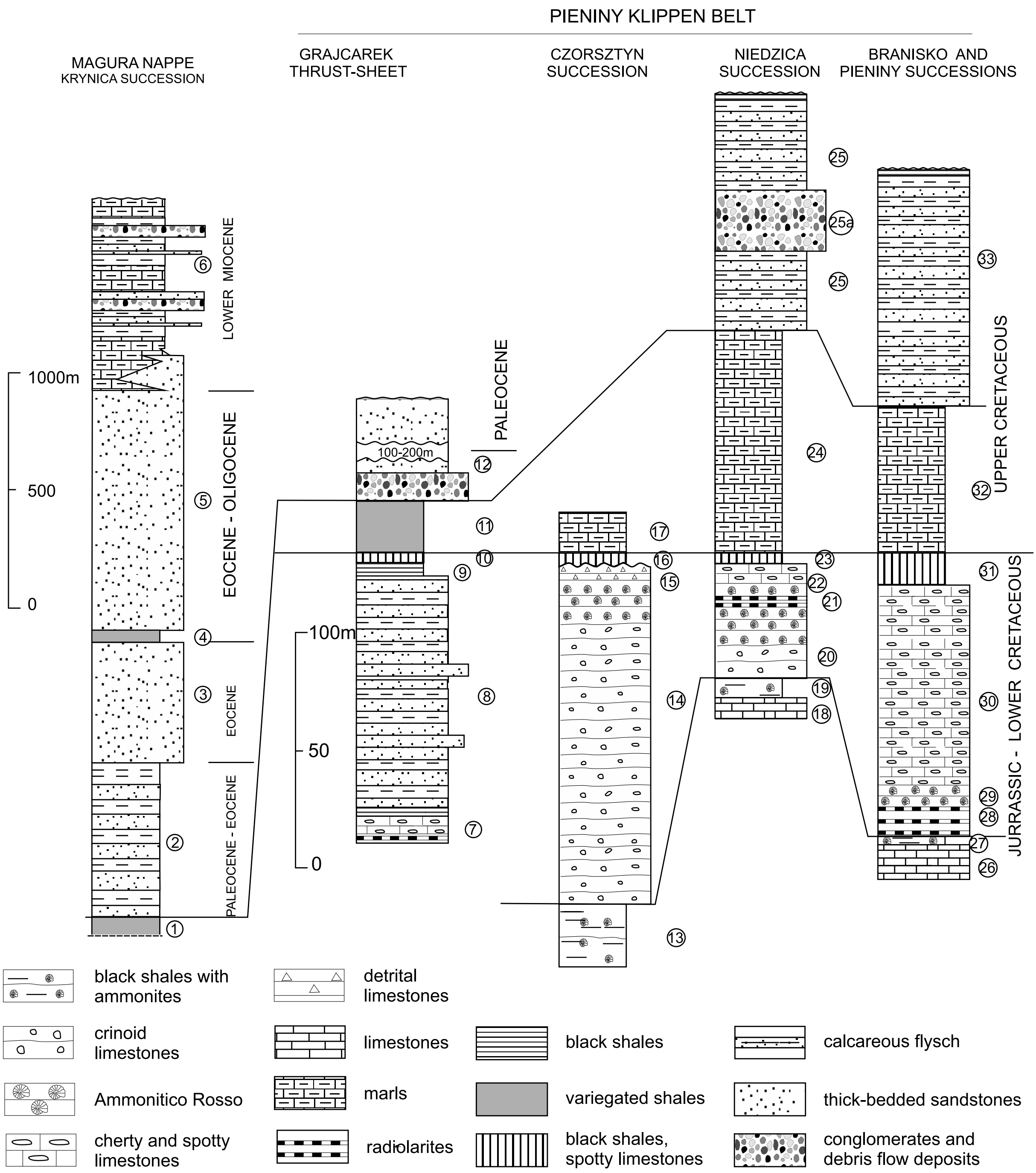
The comparison of exotic pebbles of the Jarmuta conglomerates from the Biała Woda and Czarna Woda sites shows their completely different lithological composition. The main differences are in the content of carbonate rocks: 66% in the Czarna Woda conglomerates and only 15% in the Jarmuta conglomerates. Consequently, the Czarna Woda conglomerates do not probably belong to the Jarmuta Fm. of the Grajcarek (Šariš) Unit. This is also confirmed by the presence in the Czarna Woda conglomerates of clasts whose age is younger than that of the Jarmuta Fm., i.e. clasts of middle/upper Eocene algal limestones (see section A), and Eocene calcareous nannoplankton occurs in the matrix of the conglomerates (section B, this paper). The difference also concerns the Berriasian radiometric age of the Biała Woda basaltic body (140 ±8 Ma, Birkenmajer and Pécskay 2000) and the Barremian/Albian ages of clasts from the exotic, magmatic rocks of the Czarna Woda conglomerates (106.7 ±3.2; 120.9 ±3.6; 121.5 ±3.6; 125.4 ±3.8; 128.0 ±3.8 and 128.6 ±41.1; Poprawa *et al.* 2013). The provenance of these exotic rocks, derived from the SE margin of the Magura Basin, can be probably connected with the NW part of the Tisza-Dacia Mega-Unit.

GEOLOGICAL SETTING

The Małe Pieniny Mts. belong to the PKB, a 600 km long suture zone (Text-figs 1B, 2), which separates the accretionary wedges of the Central Western Carpathians (CWC) from those of the Outer Western Carpathians (OWC). Along the northern border of the Małe Pieniny Mts., the PKB is separated from the Magura Nappe, by a narrow, strongly tectonically deformed zone, belonging to the Grajcarek Unit



Text-fig. 2. Geological map of the Małe Pieniny Mts. and southern slope of the Beskid Sądecki Range (based on Oszczypko and Oszczypko-Clowes 2014, 2017).



Text-fig. 3. Lithostratigraphic logs of the Małe Pieniny Mts. (PKB) and Krynica subunit of the Magura Nappe in the Beskid Sądecki Range (after Oszczypko and Oszczypko-Clowes 2014, supplemented). Magura Nappe – Krynica succession: 1 – Malinowa Sh. Fm., 2 – "Szczawnica"/ Ropianka and Zarzecze fms, Magura Fm.; 3 – Piwnicza Ss. Mb. 4 – Mniszek Sh. Mb., 5 – Poprad Ss. Mb. Mb. 6 – Kremna Fm.; Grajcarek thrust-sheets: 7 – Czajakowa and Sokolica Rad. fms, Czorsztyn and Pieniny Lm. fms, and Kapuśnica and Wronine fms, 8 – Szlachtowa Fm., 9 – Opaleniec Fm., 10 – Cenomanian Key Horizon, 11 – Malinowa Sh. Fm., 12 – Jarmuta Fm.; Klippen successions (partly after Birkenmajer, 1977): Czorsztyn succession: 13 – Skrzypne Sh. Fm., 14 – Smolegowa Lm. Fm. and Krupianka Lm. Fm., 15 – Czorsztyn, Dursztyn, Lysa and Spis Limestones fms, 16 – Chmielowa and Pomiedznik fms, 17 – Jaworki Marls; Niedzica succession: 18 – ?Krempachy Marl Fm., 19 – Skrzypne Sh. Fm., 20 – Smolegowa, Krupianka and Niedzica Limestone fms, 21 – Czajakowa Rad. Fm., 22 – Czorsztyn and Dursztyn Limestone fms, Pieniny Limestone Fm., 23 – Kapuśnica Fm., 24 – Jaworki Marl Fm., 25 – Sromowce Fm., 25 a – Bukowiny Gravelstone Mb.; Branisko and Pieniny successions: 26. – ?Krempachy Marl Fm., 27 – ?Skrzypny Sh. Fm., 28 – Czajakowa and Sokolica Rad. fms, 29 – Czorsztyn Lm. Fm., 30 – Pieniny Lm. Fm., 31 – Kapuśnica Fm., 32 – Jaworki Marl Fm., 33 – Sromowce Fm.

(Birkenmajer 1977, 1979; Birkenmajer and Gedl 2015 and references therein, Golonka and Rączkowski 1981, 1984; Oszczypko *et al*. 2012; Oszczypko and Oszczypko-Clowes 2014, 2017; see also Text-fig. 2), known also as the Šariš Unit (Plašienka 2012; Plašienka *et al*. 2012; Plašienka and Soták 2015) or Šariš Transition Unit (Jurewicz 2018).

From the pioneering work of Uhlig (1907) and his "Nordliche Flysch Zone" throughout the twentieth century, there was a profound conviction that the PKB is bounded on the north by the oldest flysch deposits of the Magura Nappe. At that time, the Szczawnica/Ropianka Fm., was regarded as the oldest unit of the Magura Succession: Paleocene/lower Eocene (Birkenmajer and Oszczypko 1989). Higher up in the profile, these deposits are overlain by the middle/upper Eocene Magura Sandstone Fm., 1500–1600 m thick, forming the highest parts of the Gorce and Beskid Sądecki Ranges (Watycha 1975; Burtan *et al*. 1981; Golonka and Rączkowski 1981, 1984; Kulka *et al*. 1987; Birkenmajer and Oszczypko 1989).

Our recent studies (Oszczypko *et al*. 2005b; Oszczypko and Oszczypko-Clowes 2010, 2014, 2017) documented that deposits previously described as the Szczawnica Fm. (Paleocene/early Eocene) and Zarzecze Fm. (early Eocene), located at the front of the Małe Pieniny Mts., belong to the Oligocene/early Miocene of the Kremna Fm., the youngest deposits of the Magura Succession in the Krynica subunit. The age of the Kremna Fm. remains controversial since Jurewicz (2018) and Jurewicz and Segit (2018) recently supported the concept of the Szczawnica Fm. (Kremna Fm. in this paper), documenting its early Eocene age, based on dinoflagellates. Nonetheless, the present authors sustain their opinion on the late Oligocene/early Miocene age of the Kremna Fm., which is firmly based on planktonic foraminifera and calcareous nannoplankton identified in several sections (see Oszczypko *et al*. 2005b; Oszczypko-Clowes 2010; Oszczypko-Clowes *et al*. 2018).

The prolongation of the Kremna Fm. to the west of the Dunajec River is a kind of flower structure located between the Magura Nappe and the PKB (Oszczypko-Clowes *et al*. 2018). These deposits occupy the morphological deflection between the Gorce and the PKB in the north and south, respectively (Text-fig. 2). East of the Dunajec River, the Kremna Fm. is well exposed in the upper courses of the Biała Woda, Czarna Woda, Stary, Sielski and Sopotnicki streams, on the southern slope of the Beskid Sądecki Range (Text-fig. 2). East of the Stary Stream, flysch deposits of the Kremna Fm. contain thick layers of exotic conglomerates, formerly regarded as the Jarmuta Fm. (Birkenmajer 1979; Birkenmajer *et al*. 1987; Krobicki and Olszewska 2005). From the south, the Kremna Fm. is overthrust by the Grajcarek (Šariš) Unit of the PKB (Oszczypko and Oszczypko-Clowes 2014, 2017; Oszczypko-Clowes *et al*. 2018). This unit is composed of Jurassic–Upper Cretaceous/?Paleocene pelagic and flysch formations, which were deposited in the southernmost part of the Magura Basin, and then during the Paleocene incorporated into the PKB. These deposits occur both at the front of the klippen nappes as well as in the tectonic windows inside the PKB (Oszczypko and Oszczypko-Clowes 2017).

The klippen units of the Małe Pieniny Mts. are composed of the Jurassic–Early Cretaceous carbonate formations belonging to the Czorsztyn, Niedzica, Czertezik, Branisko and Pieniny successions, overlain by Late Cretaceous variegated marls and thin-bedded flysch deposits (Oszczypko *et al*. 2010). These successions are incorporated into two larger nappes: the Pieniny Nappe (higher) and the Czorsztyn Nappe (lower). The Pieniny Nappe was initially emplaced onto the Czorsztyn Nappe, then jointly thrust over the Grajcarek (Šariš) thrust-sheets and finally refolded all together. In the early Miocene, the PKB nappes were thrust over the Krynica subunit of the Magura Nappe. Further tectonic deformations took place in the middle Miocene. This was accompanied by retroshariage and the development of strike-slip faults along the Magura Nappe and the Grajcarek thrust-sheets boundary as well as at the boundary between the PKB and the Central Western Carpathian Block. Because of these deformations, a kind of flower structure developed between the PKB and Krynica subunit of the Magura Nappe (Oszczypko and Oszczypko-Clowes 2017; Oszczypko-Clowes *et al*. 2018). Subsequent post-collision collapse was associated with the development of transversal faults and andesite intrusions.

MATERIAL AND METHODS

Micropaleontological and microfacies investigations comprised study of 80 samples (only clasts) collected from three localities: Jaworki (A), Czarna Woda (B) and Rusinowski Wierch (C) (Text-figs 2, 3). The majority of the studied clasts represents various types of calcareous sediments, while non-sedimentary rocks are sporadic. Identification of microfacies was based on Dunham's revised classification (Wright 1992). The classification of the mixed siliciclastic and carbonate rocks was based on Mount (1985). The most frequent microfacies

Text-fig. 4. Conglomerates of the Jarmuta Fm. (Maastrichtian–?Paleocene). A – the Lower Cretaceous basaltic body in the Jarmuta Fm. (Biała Woda Stream). B – the Jarmuta conglomerates (Maastrichtian/Paleocene) in the Biała Woda Stream. C – Jarmuta conglomerates, outflow of the Jasielnik Stream to the Grajcarek Stream at Szlachtowa, hammer 32 cm long. D – detail of C (13 cm long pen, as the scale).

types recognized were packstones or wackestones with foraminifera and wackestones with radiolarians or sponge spicules. Allochemic sandstones or mudstones, rudstones, grainstones or micritic limestones are subordinate. Foraminifera were the most common components of the identified assemblages. Calcitized radiolarians and sponge spicules were frequent in some samples. Calcareous dinocysts, ostracods, pelagic crinoids, bryozoans and calcareous algae rarely occur. Some samples were devoid of fossils or contained non-identifiable organic fragments. The specific compositions of the assemblages analysed suggest that they represent both shallow-marine (Triassic, Barremian–Aptian, Paleogene) and open sea (Jurassic) environments. The latter assemblages quantitatively prevail. Thin sections were examined under the Labophot 2-pol Nikon polarizing microscope. The microphotographs of microfossils were taken at the Institute of Geological Sciences – Jagiellonian University, with the aid of the Nikon photomicrographic device NIS-elements connected with the Eclipse LV 100-pol polarizing microscope.

STUDIED SECTIONS

The Czarna Woda conglomerates have been recognized along the southern slope of the Beskid Sądecki Range (Text-fig. 2), between the Stary (W) and Jasielnik streams (E). Toward the east, this type of conglomerate was reported by Kutyba (1986) in the Rogacz Stream. The entire section sampled is located north of a tectonic contact between the Grajcarek Unit and the Magura Nappe (Text-fig. 2). From the south, these conglomerates are bounded by the frontal thrust of the Grajcarek Unit. South of the Grajcarek Valley, small exposures of the Czarna

Woda conglomerates, known also as Złatne conglomerates, have also been recognized in the tectonic windows within the Kremna Fm. (Oszczypko and Oszczypko-Clowes 2017).

Jaworki (GPS Way Point (WP) 250)

This section is located along the field road crossing a watershed ridge, between the Stary (W) and Czarna Woda (E) streams (Text-fig. 2). At the fork of the road, a tectonic contact between the red shales of the Malinowa Fm. (Upper Cretaceous) of the Grajcarek Unit and the thick bedded sandstones and conglomerates of the Kremna Fm. (Oligo/Miocene) of the Magura Nappe is exposed. Going along the road toward the north, the exotic pebbles are very well visible over a 200 m distance. They are dominated by carbonate clasts of different size (mainly dark spotty limestones), often spheroidal (4×3×2 to 11×4×3 cm). Clasts of metamorphic rocks (up to 15×10×2cm in diameter) are very rare. In addition to the exotic pebbles, there were also weathered fragments of the Magura-type sandstones. The conglomerates of probably exotic derivation form lenses in thick-bedded sandstones. The lithological inventory of the conglomerates consists of metamorphic vein quartz 16%, Paleogene rudstones 8%, Triassic wackstones 8%, limestones of the Urgonian platform 30% and spiculite/sponge “filament” limestones 38%.

Czarna Woda (GPS WP 531)

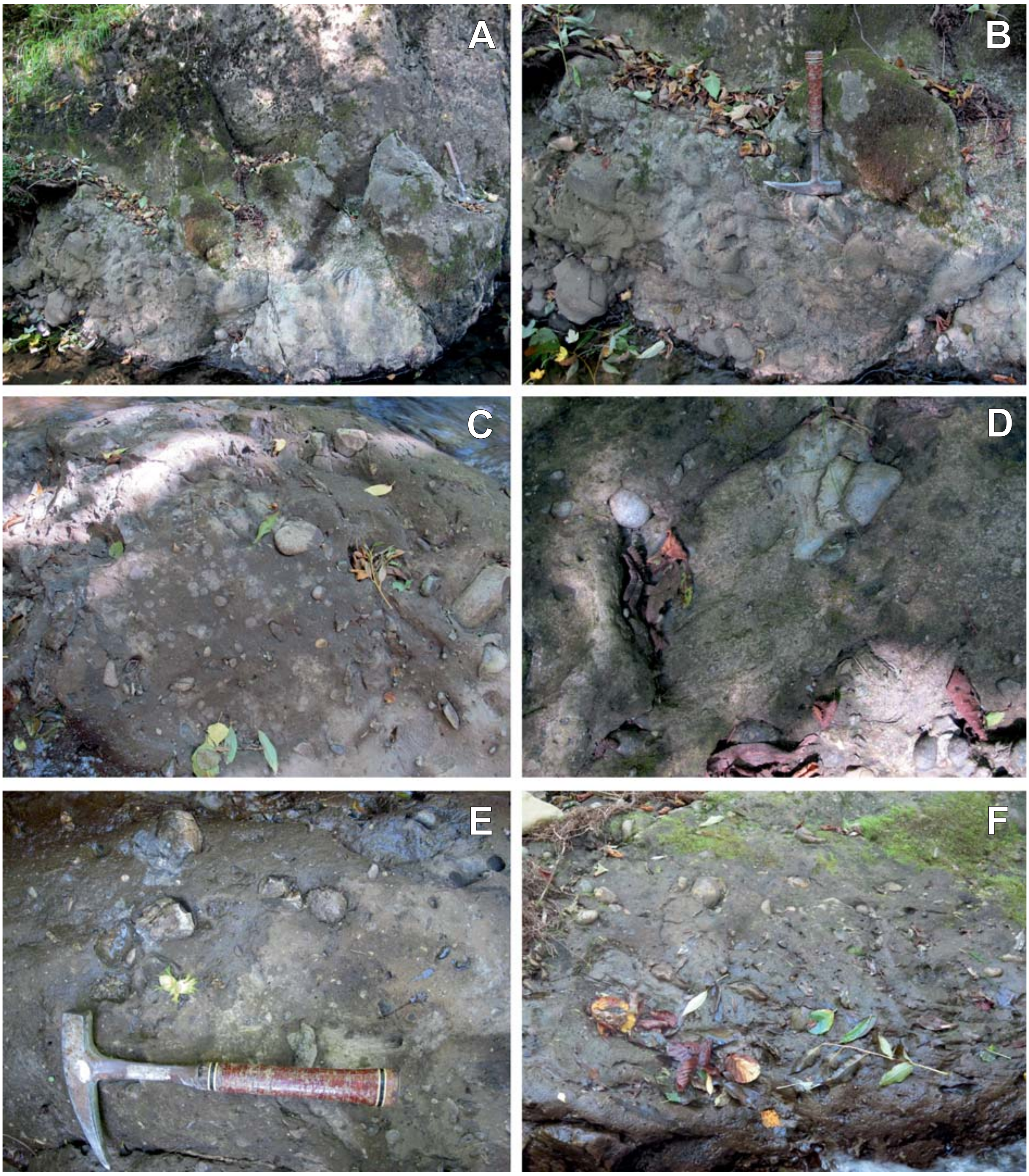
This section is located in the Czarna Woda Stream, exactly above the first road bridge and footbridge (Text-fig. 2). These conglomerates were previously described as the Jarmuta Fm. (Kutyba 1986; Birkenmajer *et al*. 1987; Birkenmajer and Dudziak 1991; Krobicki and Olszewska 2005). At the base of exposure, there is a 5 m thick, massive thick-bedded, north dipping (15/25 in normal position) layer of gravel/sandy turbidites (Table 1, WP 534, Text-fig. 5). The lower part of the bed is composed of pebbles of a few centimetres in diameter, suspended in a dark sandy matrix. Higher up the profile, the thick-bedded sandstone is overlain by a c. 2 m thick layer of dark pebbly mudstones (WP 531/532). They consist of spindle dominated pebbles (Text-fig. 5), with a diameter from 10×7×2 to 4×3.5×1.3 cm. The upper part of this layer contains various exotic clasts: crystalline rocks – 16%, filament limestones, radiolarian shales and spiculites – 28%, the Urgonian type limestone – 12%, Paleogene limestones – 4%, Triassic limestones – 4%, undetermined limestones – 28%, undetermined samples – 8%. In the lower part of the layer, there are clasts containing spiculite ?filaments, planktonic crinoids of the genus *Saccoma* and also Urgonian type limestones. Still higher in the section, there are the NNE dipping (15°/15° in a normal position) thin-bedded turbidities exposed. These rocks were formerly considered to represent the Szczawnica beds (late Paleocene/early Eocene, see Alexandrowicz *et al*. 1984; Golonka and Rączkowski 1984) or the Szczawnica Fm. (Birkenmajer and Oszczypko 1989), see also Jurewicz and Segit (2018).

Locality name	Samples	GPS cordinate
Sielski Stream	WP242/1-6/2010	N49 24.881 E20 31.664
Sielski Stream	WP78/2012	N49 25.292 E20 31.919
Sielski Stream	WP79/2012	N49 25.302 E20 31.924
Stary Stream	WP329/2010	N49 24.757 E20 32.952
Stary Stream	WP330/A-E/2010	N49 24.760 E20 32.958
Stary Stream	WP333/2010	N49 24.775 E20 33.004
Stary Stream	WP337/2010	N49 24.950 E20 33.169
Rusinowski Wierch	WP486	N49 24.681 E20 34.050
Rusinowski Wierch	WP489	N49 24.601 E20 33.669
Rusinowski Wierch	WP485	N49 24.682 E20 34.077
Czarna Woda (B)	WP531	N49 24.765 E20 33.762
Czarna Woda (B)	WP381	N49 24.767 E20 29.212
Czarna Woda (B)	WP385	N49 25.016 E20 29.293
Biała Woda (D)	WP77	N49 23.826 E 20 35.309
Jaworki (A)	WP 250	N49 38.530 E19 25.273

Table 1. GPS coordinates of exposures documenting the age of the Magura Succession and Kremna Fm. (Oszczypko and Oszczypko-Clowes 2010; Oszczypko-Clowes *et al*. 2018).

Rusinowski Wierch (GPS WP 486)

East of Jaworki Village, the tectonic contact of the Grajcarek/Šariš Unit (south) with the Kremna Fm. of the Magura Nappe (north) was well recognized (Oszczypko and Oszczypko-Clowes 2017; see Text-fig. 2). This thrust-fault runs from the Jasielnik Stream (east) to the Czarna Woda Stream (west), roughly along the high voltage line (Text-fig. 2). In a dirt road, (WP 489) the tectonic contact (overthrust) of red shales of the Malinowa Fm. (Upper Cretaceous), belonging to the Grajcarek/Šariš Unit, over the southeast dipping Kremna Fm. (Oligocene–Miocene) is well visible. The next exposure of the Kremna Fm. appears near a chapel (602 m a.s.l.) and along a road from Czarna Woda to the Rusinowski Wierch (Text-fig. 2). Grey marly mudstones with



Text-fig. 5. The Czarna Woda conglomerate at the locus typicus: Czarna Woda Stream, above the road and foot bridges. A – thick-bedded (5 m), coarse-grained sandstones, with lenses of exotic pebbles at the base (left corner of the photo). B – detail of Text-fig 4A – well-rounded conglomerates, up to 15 cm in diameter, hammer 32 cm long as a scale. C, D – dark mudstone matrix supported conglomerates at the top of the thick-bedded sandstone. E – the same conglomerate c. 10 m beneath the bridge. F – Czarna Woda Stream, conglomerates, below the bridge.

intercalations of thin- to medium-bedded, crushed sandstones, dipping to the north (350/60, in an overturned position) are well exposed along the road. Higher up in the trail, at the WP 486, a 5 m thick bed of conglomerates is exposed. The conglomerates are dominated by carbonate exotic pebbles, mainly spotty limestones as well as crinoidal and glauconitic limestones. The diameter of the pebbles, often discoidal, ranges from 25 to 10–5 cm. The pebbles are composed of radiolarian shales and filament limestones with numerous elements of sponge (63%), limestones of the Urgonian carbonate platform (22%) and Triassic limestones (3.7%). Additionally, there are clasts of crystalline rocks (11.3%). The matrix consist of dark-grey marly mudstone. Sill higher, there occurs a c. 6 m thick layer containing metamorphic pebbles: grey and red quartzites, vein quartz and gneisses. The size of these clasts oscillates between 7×7×5 and 3×3×1.5 cm. Additionally, we recognized a small block (17×10×5 cm) of dark, massive volcanic rock.

Biała Woda, Brysztan Creek (GPS WP 77)

In this section, thick-bedded turbiditic sandstones of the Kremna Fm. with laminated mudstone (grainstone) and *Chondrites* on the top section are exposed at a tectonic contact with the PKB.

The age of the Czarna Woda conglomerates

Exotic-clast-bearing conglomerates from the Czarna Woda section occur in the form of lenses within the thick bedded sandstones of the Kremna Fm. The Oligocene–Miocene age of this formation has been documented mainly by calcareous nannoplankton (Oszczypko-Clowes 2010; Oszczypko and Oszczypko-Clowes 2010, 2014) and, to a lesser extent, by planktonic foraminifera (Oszczypko-Clowes *et al*. 2018). A typical early Miocene nannofossil assemblage is shown in Text-fig. 6. The early Miocene age – NN2 was documented in a few localities (Text-fig. 2, Table 1): Szlachtowa (WP 242/1-6/2010), Czarna Woda (WP 329, 330/331, 337/2012) and the Jasielnik Stream (WP 385/381/20012).

The NN2 assignment is based on the co-occurrence of the following species: *Sphenolithus conicus*, *S. disbelemnos*, *Reticulofenestra pseudoumbilica* and *Triquetrorhabdulus carinatus*. At the same time *Dictyococcites bisectus*, *Cyclicargolithus abisectus* and *Zygrhablithus bijugatus* are absent from this association. According to Young (1998), the first occurrence of *S. disbelemnos* and/or *Umbilicosphaera rotula* are reliable biostratigraphical events, characteristic of the lower limit of the NN2 Zone. The absolute age of *S. disbelemnos* was established by Shackleton *et al*. (2000) at 22.67 Ma and it is an important datum level for the Paratethys region (Rögl and Nagymarosy 2004; Oszczypko-Clowes in Oszczypko *et al*. 2005b). The same early Miocene age of the Czarna Woda conglomerates has been supported by small foraminifera from the samples collected in the Sielski Stream (WP242/1–6/2010), west of section A (Oszczypko-Clowes *et al*. 2018).

MICROFACIES ANALYSES

Watershed between the Stary and Czarna Woda Streams

Foraminiferal wackestones, rudstones, micritic limestones and spiculites yielded microfossils of diversified age (Table 2A, Text-figs 7, 8). The oldest assemblages contained poorly preserved *Nodosariidae*, sponge spicules and ostracods. They probably represent Mesozoic (Triassic–Jurassic). The youngest (middle–late Eocene) assemblage contained (among others) *Maslinella chapmani* Chapman et Wade, *Pararotalia lithothamnica* Uhlig, *Victoriella* sp. More frequent were Barremian–Aptian microfossils composed of carbonate platform foraminifera. Typical species, such as *Debarina hahounerensis* Fourcade, Raoult et Villa, *Sabaudia minuta* Hofker, *Nezzazata isabella* Arnaud-Vanneau and Sliter occur in all assemblages. A singular occurrence of cysts of carbonate dinoflagellate *Crustocadosina semiradiata* (Wanner) has been also recognized. The majority of microfossils are characteristic of the neritic environment.

Czarna Woda Stream

Samples from this section represented more diversified microfacies. They encompassed foraminiferal and radiolarian wackestones, foraminiferal grainstones, allochemic sandstones and mudstones, and sparitic limestones. The microfossil content of the investigated samples was similar to that in the Jaworki section (Table 2B, Text-figs 7, 8). The oldest assemblage, containing specimens of the foraminiferal genus *Aulotortus,* represents Triassic. The assemblage of the secundibranchia of the planktonic crinoid *Saccocoma* was assigned to Kimeridgian–Tithonian. Diversified foraminiferal assemblages of Barremian–Aptian age represent ubiquitous Urgonian facies. The youngest Palaeogene assemblages are composed of shallow water species such as *Haddonia heissigi* Hagn, *Planorbulina cretae* (Marsson) and rare *Globigerina* sp. The red algae fragments usually belong to the Palaeogene assemblages. Microfossils from the Czarna Woda section represent both neritic and pelagic environments.

A. Jaworki, watershed between the Stary and Czarna Woda streams

Microfossils	Paleogene	Barremian–Aptian	Triassic	Environment
Maslinella chapmani	×			open shelf
Haddonia heissigi	×			open shelf
Pararotalia lithothamnica	×			open shelf
Victoriella	×			open shelf
Discocyclina sp.	×			open shelf
Distichoplax biserialis	×			open shelf
Bolivinopsis goletorum		×		carbonate platform
Debarina hahounerensis		×		carbonate platform
Nautiloculina bronnimanni		×		carbonate platform
Earlandia? brevis		×		carbonate platform
Nezzazata isabella		×		carbonate platform
Pfenderina aureliae		×		carbonate platform
Sabaudia minuta		×		carbonate platform
Scythiloculina bancilai		×		carbonate platform
Vercorsella arenata		×		carbonate platform
Quinqueloculina robusta		×		carbonate platform
Pseudonummuloculina urigerica		×		carbonate platform
Crustocadosina semiradiata		×		open sea
Spirillina sp.			×	shelf
Nodosaria sp.			×	shelf

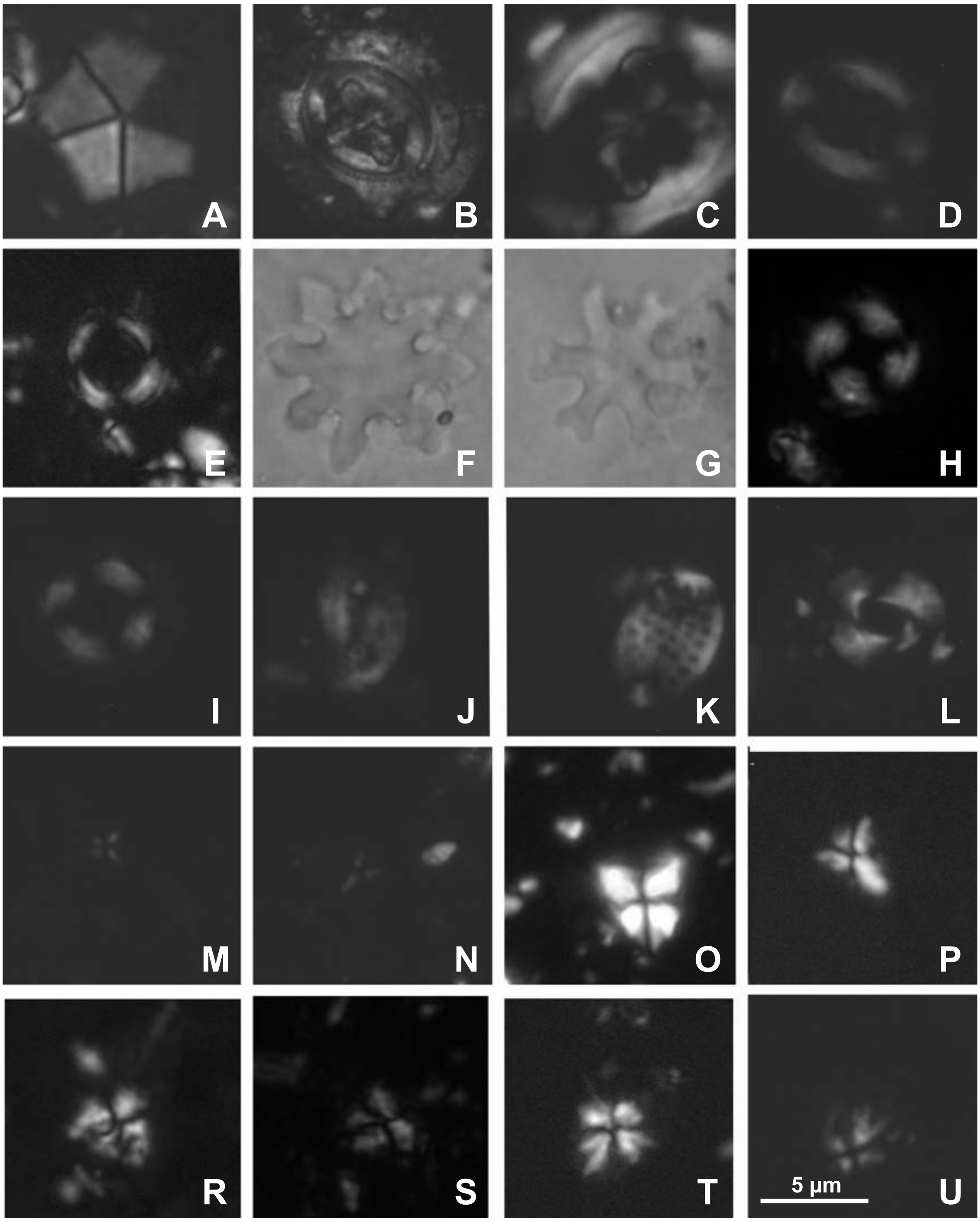
B. Czarna Woda Stream

Microfossils	Paleogene	Barremian–Aptian	Doggerian–Malmian	Triassic	Environment
Tenuitella sp.	×				pelagic
Globigerina sp.	×				pelagic
Haddonia heissigi	×				open shelf
Planorbulina cretae	×				open shelf
Distichoplax biserialis	×				open shelf
Novalesia product		×			carbonate platform
Debarina hahounerensis		×			carbonate platform
Glomospira urgoniana		×			carbonate platform
Rumanoloculina ponticuli		×			carbonate platform
Sabaudia minuta		×			carbonate platform
Nezzazata Isabella		×			carbonate platform
Bolivinopsis labeosa		×			carbonate platform
Everticyclammina hedbergi		×			carbonate platform
Arenobulimina cochleata		×			carbonate platform
Istriloculina elliptica		×			carbonate platform
Palorbitolina lenticularis		×			carbonate platform
Saccocoma sp.			×		pelagic
Spumellaria sp. “filaments”			×		pelagic
Aulotortus sp.				×	shelf
Spirillina sp.				×	shelf

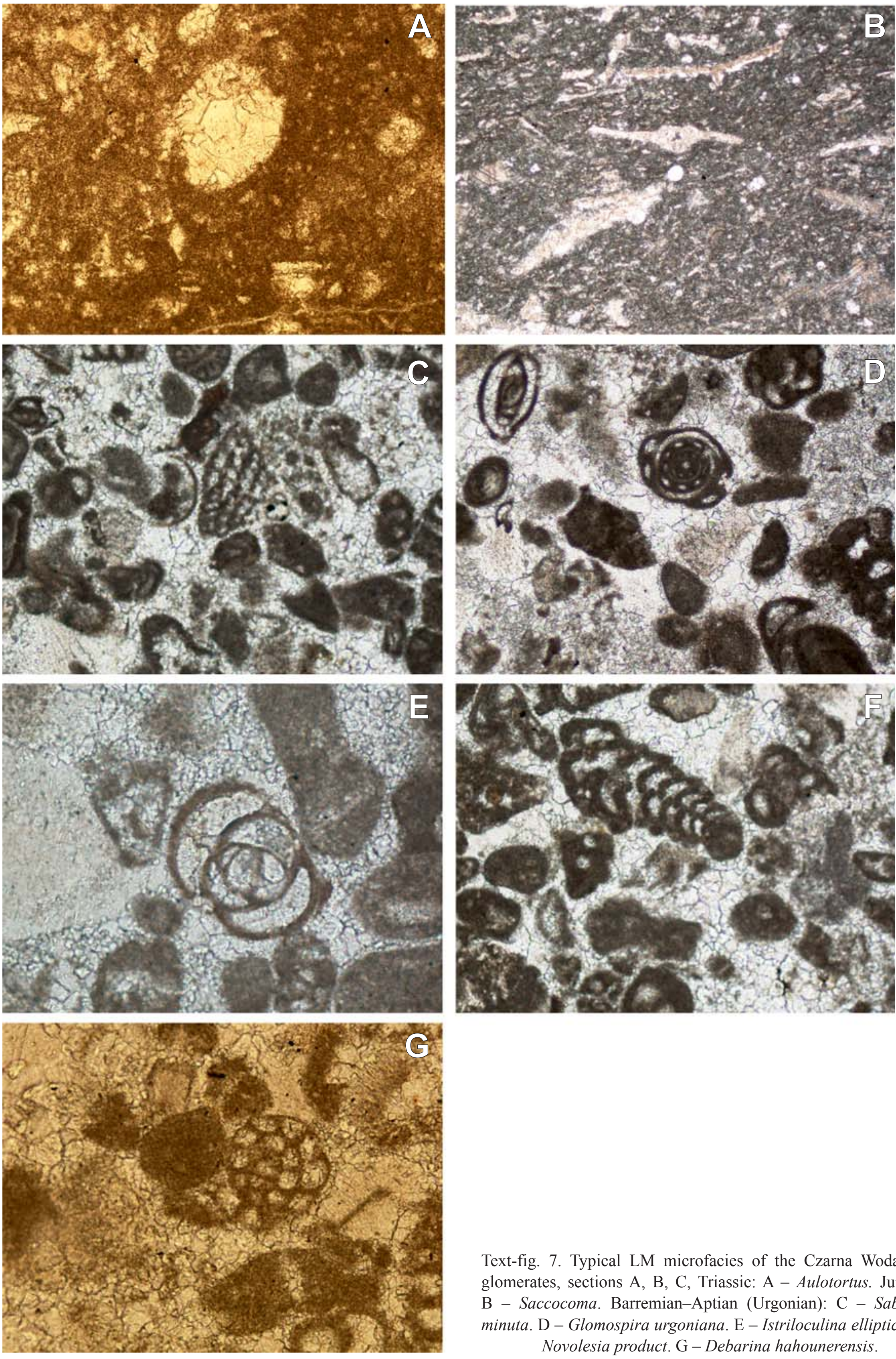
C. Rusinowski Wierch

Microfossils	Barremian–Aptian	Jurassic	Triassic	Environment
Debarina hahounerensis	×			carbonate platform
Glomospira urgoniana	×			carbonate platform
Novalesia producta				carbonate platform
Rumanoloculina ponticuli	×			carbonate platform
Sabaudia minuta	×			carbonate platform
Lenticulina sp.		×		open shelf
Frondicularia sp.			×	open shelf
Nodosaria sp.			×	open shelf
Radiolarians				pelagic

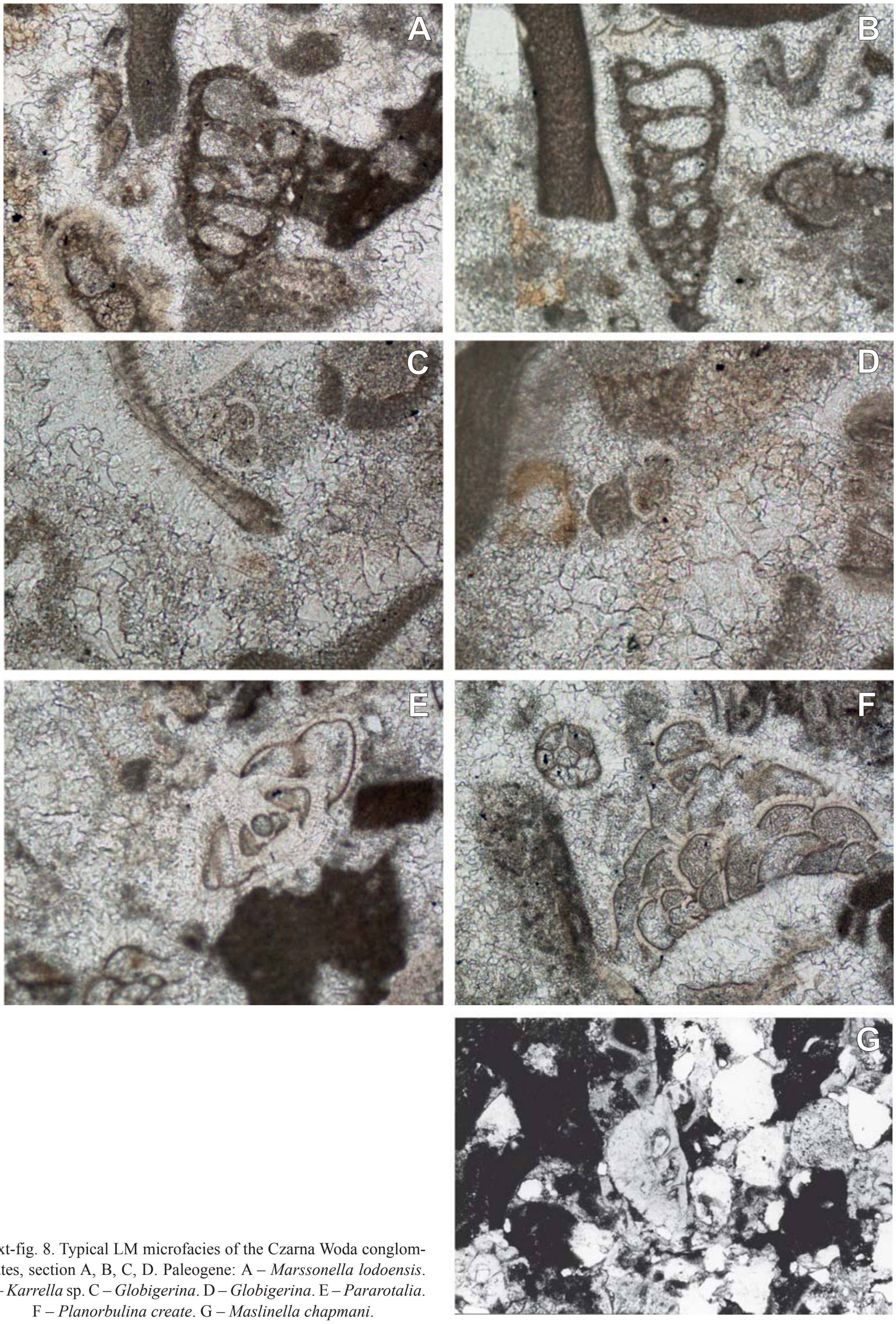
Table 2. Results from microfacies analyses.



Text-fig. 6. Calcareous nannoplacton LM microphotographs of typical species, scale bar is the same for all photographs (Oszczypko and Oszczypko-Clowes 2010). **A** – *Braarudosphaera bigelowii*, Kremna Fm., sample WP242/1/2010. **B** – *Chiasmolithus gigas*, Kremna Fm., sample WP329/2010. **C** – *Chiasmolithus grandis*, Kremna Fm., sample WP330/B/2010. **D** – *Chiasmolithus solitus*, Kremna Fm., sample WP330/B/2010. **E** – *Coronocyclus nitescens*, Poprad Sandstone Mb. of the Magura Fm., sample BW 505-1. **F** – *Discoaster binodosus*, Kremna Fm., sample WP330/C/2010. **G** – *Discoaster deflandrei*, Kremna Fm., sample 104b/2010. **H** – *Ericsonia formosa*, Kremna Fm., sample 9/07/N. **I** – *Ericsonia robusta*, Kremna Fm., sample WP917/2/2011. **J** – *Helicosphaera compacta*, Poprad Sandstone Mb. of the Magura Fm., sample BW 505-2. **K** – *Ponthosphaera multipora*, Kremna Fm., sample H 1. **L** – *Reticulofenestra dictyoda*, Kremna Fm., sample WP79/2007. **M**, **N** – *Sphenolithus calyculus*, Kremna Fm., sample WP330/C/2010. **O** – *Sphenolithus conicus*, Kremna Fm., sample 104b/2010. **P** – *Sphenolithus delphix*, Bukry, Magura Fm., sample BW 1. **R**, **S** – *Sphenolithus disbelemnos*, Kremna Fm., sample WP633/2011. **T**, **U** – *Sphenolithus dissimilis*, Kremna Fm., sample 104c/2010.



Text-fig. 7. Typical LM microfacies of the Czarna Woda conglomerates, sections A, B, C, Triassic: A – *Aulotortus*. Jurassic: B – *Saccocoma*. Barremian–Aptian (Urgonian): C – *Sabaudia minuta*. D – *Glomospira urgoniana*. E – *Istriloculina elliptica*. F – *Novolesia product*. G – *Debarina hahounerensis*.



Text-fig. 8. Typical LM microfacies of the Czarna Woda conglomerates, section A, B, C, D. Paleogene: A – *Marssonella lodoensis*. B – *Karrella* sp. C – *Globigerina*. D – *Globigerina*. E – *Pararotalia*. F – *Planorbulina create*. G – *Maslinella chapmani*.

Rusinowski Wierch

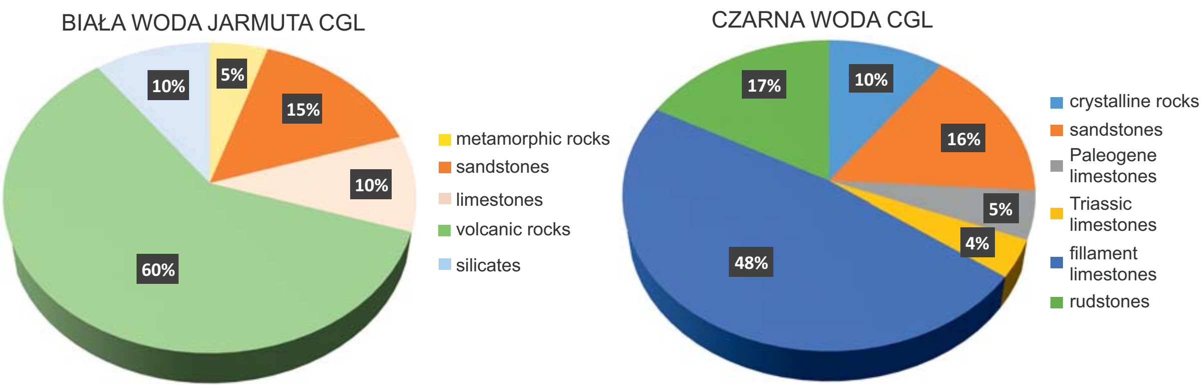
The microfacies characteristic of the investigated samples from this section essentially does not differ from those previously described. Similar also is the microfossil content (Table 2C, Text-figs 7, 8). The only differences are strong calcification of all samples making identification of fossils relatively difficult and the lack of Palaeogene forms. More distinct only were foraminiferal assemblages of the Urgonian type. These assemblages comprise not only forms suggesting a Jurassic age (*Lenticulina* sp., radiolarians) but also Triassic (*Frondicularia* sp., *Nodosaria* sp., snails). The microfossils identified represent a neritic environment.

Biała Woda, Brysztan Creek, a new bridge

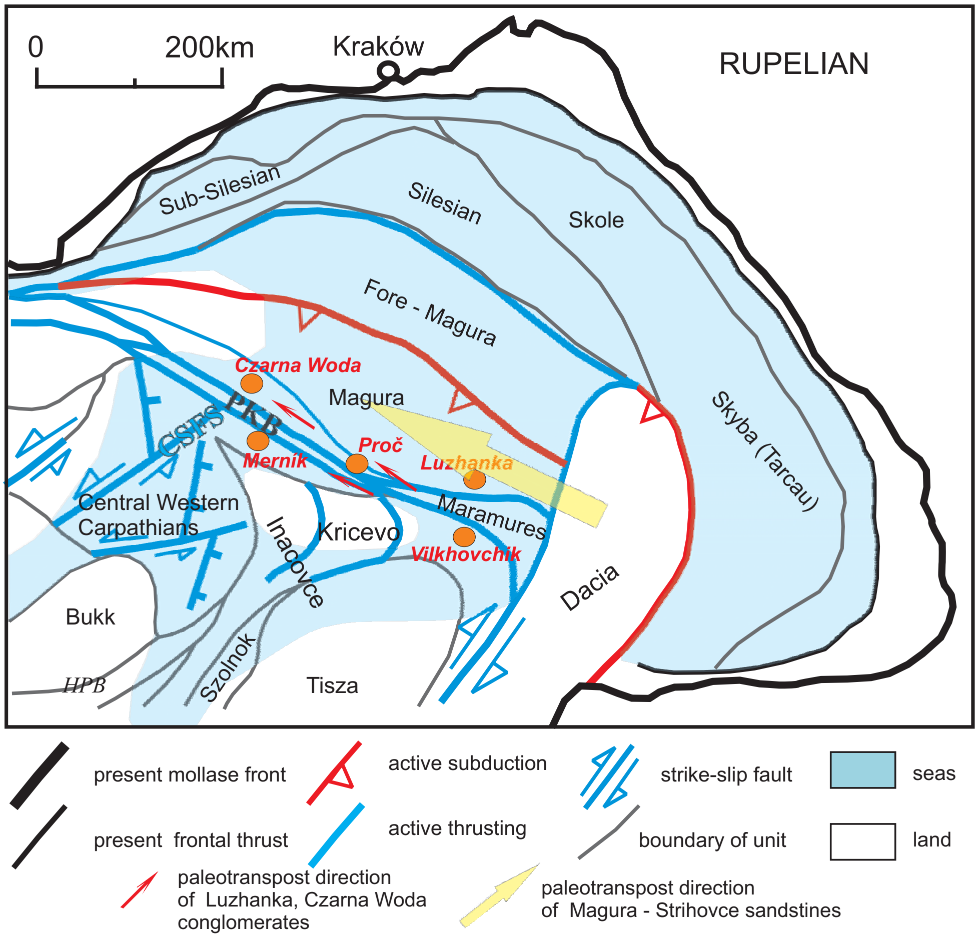
The foraminifera assemblage from these pebbles is characterized by the presence of *Dorothia traubi* Hagn, *Clavulina* cf. *parisiensis* d'Orbigny, *Textularia* cf. *minuta* Terquem, *Pararotalia lithothamnica* (Uhlig), *Acarinina* cf. *rotundimarginata* Subbotina, *Turborotalia* cf. *cerroazulensis* (Cole), *Subbotina linaperta* (Finlay), *Tenuitellinata* sp., *Globanomalina* sp., miliolids (numerous, crushed). The association is complemented by fragments of red algae. The assemblage suggests middle–late Eocene age. Stratigraphic investigations of all 80 samples revealed that they generally represent rocks of Triassic (Middle?), Jurassic, Early Cretaceous and Palaeogene age. The microfossil content of the designated assemblages displays a certain similarity with coeval assemblages reported from the Proč, (Mišík *et al*. 1991a) and Tylicz (Olszewska and Oszczypko 2010) localities. The Urgonian-type assemblages display the greatest similarity. The youngest (middle–late Eocene) assemblages suggest post-Eocene erosion of the source area. The poor preservation of the majority of microfossils suggests that the examined pebbles may have come from older accumulations being reworked several times. A considerable part of the examined samples (Text-fig. 9) contained accumulations of microfossils (e.g. calcified radiolarians, filaments) without age-significant forms. Only those with *Saccocoma secundibranchias* spoke in favour of a Late Jurassic age. The environmental affiliations of the designated foraminifera and other microfossils indicate that they came from pelagic, outer shelf and carbonate platform environments. Collective statistics based on 80 thin sections reveals: limestone with filaments – 45%, Urgonian limestones – 17.50%, Triassic limestones – 3.75%, Paleogene limestones – 3.75%, sandstones – 12.50%, crystalline rocks – 11.25%.

DISCUSSION AND PALEOGEOGRAPHICAL IMPLICATIONS

Our research documented that the Czarna Woda conglomerates (Oligocene–Miocene), belonging to the Magura Succession, are fundamentally different from the Jarmuta conglomerates (Maastrichtian/?Paleocene) of the Grajcarek (Šariš) Unit of the PKB. These differences concern both the petrographic composition and the age of these conglomerates (Text-fig. 9). The Jarmuta conglomerates are dominated by exotic pebbles of magmatic, metamorphic and volcanic origin. Only a relatively few pebbles of carbonate rocks show a clear resemblance to the PKB carbonates (Książkiewicz 1977; Birkenmajer 1979; Birkenmajer and Wieser 1990). These conglomerates were associated with the Late–Cretaceous/Paleocene tectonic evolution of the PKB (Birkenmajer 1986). Delivery of detritus to the Jarmuta conglomerates



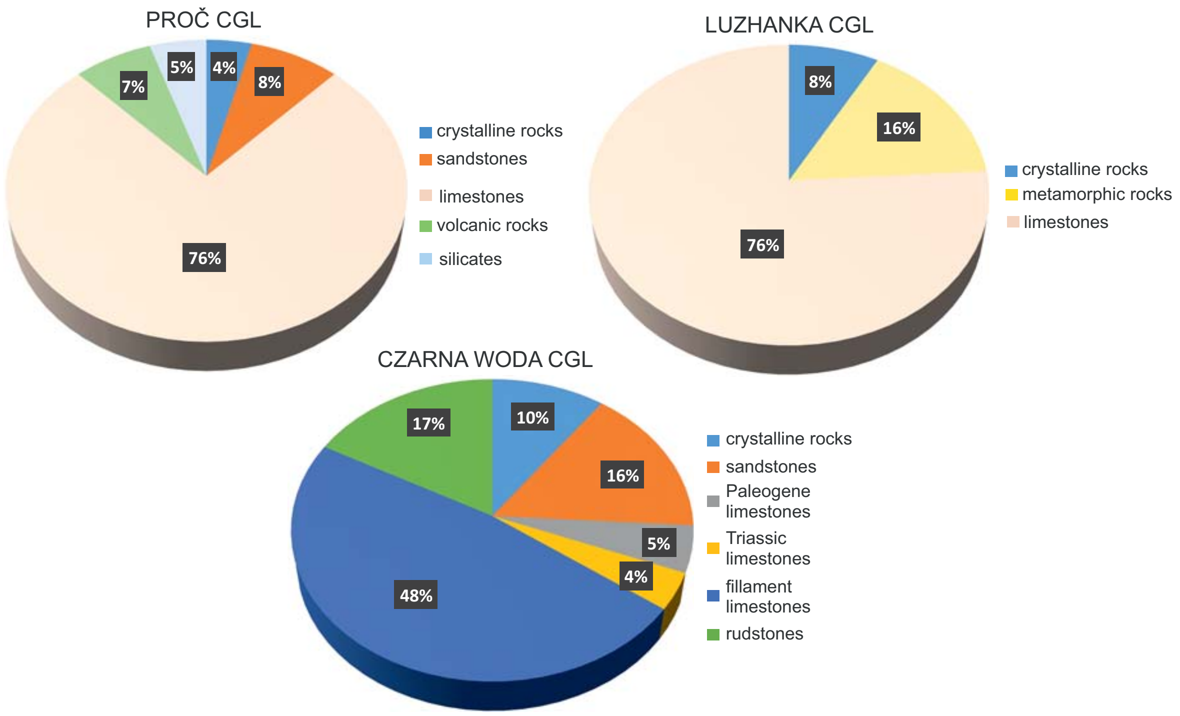
Text-fig. 9. Comparison of exotic clasts from the Biała Woda and Czarna Woda conglomerates in the Małe Pieniny Mts. (Poland, this paper).



Text-fig. 10. The Rupelian paleogeography map of the Western and Eastern Carpathians (based on Kováč *et al*. 2016).

was connected with uplift of the inner part of the Pieniny Basin and the formation of the "exotic cordillera" (Książkiewicz 1977).

During the Eocene–Oligocene and possibly also early Miocene, the PKB and the southern part of the Magura Basin were supplied from two different source areas located in the SE (Text-fig. 10). The detritus delivered to the PKB Basin was provided by the episodic "Neopieninic cordillera" (Mišík *et al*. 1991a). This source included an uplifted part of the Early/middle Cretaceous carbonate platform, composed of filament and Urgonian type limestones. Additionally, clasts of metamorphic rocks as well as Triassic and Palaeogene shallow-water limestones were supplied. The lack of exotic Jurassic limestone clasts, such as the ubiquitous calpionellide limestone, is noteworthy. It probably results from the fact that the carbonate exotic clasts were derived by erosion of a secondary source i.e. olistoliths and olistostromes of the Soymul Fm. of the Marmara Klippen Zone. The lithological inventory of the Czarna Woda conglomerates is essentially similar to that of the well-known Vilkhovchyk/Luzhanka/Proč conglomerates (Text-fig. 11). These conglomerates have been well recognized from Trans-Carpathian Ukraine and eastern Slovakia. In addition, partly similar rocks, known as the Mernik conglomerates were recognized in the middle part of eastern Slovakia along the PKB-CWC boundary (Soták *et al*. 1991). These types of conglomerate have been also recognized in the Magura Nappe, between Jarabina and the Poprad River, and in the Oligocene–?lower Miocene deposits of the Kremna Fm. (Oszczypko *et al*. 2005b). All these conglomerates were transported from the SE to the west along the axis of the PKB Basin. This is well documented by the distribution of exotic-bearing conglomerates together with flats (olistoplaques) and blocks (olistolithes) of the PKB in the Trans-Carpathians, Ukraine and eastern Slovakia



Text-fig. 11. Comparison of exotic clasts from the Proč conglomerates in eastern Slovakia (Mišik *et al.* 1991a) to those from the Luzhanka conglomerates in Trans-Carpathian Ukraine (based on Gofstein and Dabagyan 1967; Kruglov and Smirnov 1967; Černov 1973) and the Czarna Woda conglomerates in the Czarna Woda Stream (Krynica subunit of the Magura Nappe in Poland, this paper).

(see geological map of Nemčok 1990). Similar conglomerates of Oligocene–early Miocene age were recognized in this study within the Jaworki-Czarna Woda area in Poland, along a tectonic boundary between the Magura Nappe and the PKB. This justifies our conclusion that at a distance of c. 250–300 km, between Trans-Carpathian Ukraine, through eastern Slovakia and Poland, up to the Horna Orava Region in western Slovakia, exotic-clast-bearing conglomerates with similar lithological inventory are distributed in front of the PKB.

During the Paleogene, the residual PKB Basin, narrow and relatively deep with an island arc, was limited from the south and north by the Podhale and Magura basins. The PKB Basin was supplied with clastics and carbonate conglomerates of the "Marmarosh type" on a distance of up to 300 km. In the Ukrainian Carpathians, the Marmarosh Unit is usually subdivided into two subunits: the Marmarosh Klippen Zone and the Marmarosh Crystalline Massif (Oszczypko *et al.* 2005a). The basal part of the Marmarosh Klippen Zone contains the Aptian/Albian olistostromes and olistoplaques of the Sojmul Fm. (up to 1500 m thick), with the blocks of Urgonian limestones. The Eocene and Oligocene exotic-bearing conglomerates of the PKB and partly Magura Basin were probably supplied due to erosion of both the Marmarosh Klippen Zone and Marmarosh Crystalline Massif. During the middle–late Eocene and Oligocene the Magura Basin (Bystrica and Krynica subunits) was supplied from the SE. This source area, which fed the Magura Basin was located north of the of Marmarosh Unit. At the Eocene–Oligocene transition, such a paleogeographic position could have been occupied by the Tissa/Dacia Unit (Text-fig. 10), which at that time was more or less perpendicular to the Magura Basin (Kováč *et al.* 2016). This source supplied the Magura Basin with clastics and metamorphic rocks of the "Strihovce type" (Mišík *et al.* 1991b). This source area is known as the South Magura Cordillera or South Magura Exotic Ridge (Mišík *et al.* 1991b). The clastic material derived from erosion of this source area was transported to the NW to the Magura Basin and deposited as the thick-bedded turbiditic sandstones of the Magura Fm. (Eocene–Oligocene), up to 2000–2500 m thick (Birkenmajer and Oszczypko 1989). In the Polish part of the Krynica subunit, this formation was subdivided into three members: Piwniczna and Poprad Sandstones, divided by the Mniszek Shale Member (middle/upper Eocene variegated shales). In the Eocene, deposits of the Krynica zone in Poland, the thick-bedded, turbiditic sandstones, are accompanied by lenticular bodes of exotic-clast-bearing conglomerates. These conglomerates, with a significant content of igneous and metamorphic rocks differ from the Proč/Czarna Woda conglomerates. This type of conglomerates was distinguished as the "Strihovce conglomerates", derived from the South Magura Ridge (Mišík *et al.* 1991b). During the Aquitanian/Burdigalian, the PKB and Grajcarek (Šariš) Unit were thrust over the Magura and Kremna Fms. of the Krynica subunit (Plašienka and Soták 2015). The opposite situation took place in the eastern sector (e.g. Čergov Mt.), where the Krynica subunit is thrust over the PKB (Plašienka and Soták 2015). Subsequent subduction of the southern part of the Magura Basin beneath the Czarna Woda block resulted in the development of the Krynica subunit of the Magura Nappe.

CONCLUSIONS

- The Czarna Woda conglomerates are significantly different from the Jarmuta conglomerates, both in their lithological inventory and age.
- The Jarmuta conglomerates (Late Cretaceous–?Paleocene) belong to the Grajcarek (Šariš) Unit, while the Czarna Woda conglomerates (Oligocene–Miocene) belong to the Kremna Fm. of the Magura Nappe.
- During the late Eocene–Oligocene–?early Miocene, the Pieniny/Magura deep water basin existed and was filled from the SE with exotic clasts supplied from two independent source areas: (I) "Luzhanka-Proč-Czarna Woda" and (II) "Strihovce-Magura", located along the SE tectonic boundary of the Outer Carpathian Basin.
- The Czarna Woda conglomerates are dominated by a significant amount of pebbles of Mesozoic "filament" limestones. These conglomerates contain mostly Lower Cretaceous limestones of the Urgonian facies and additionally clasts of Triassic to Paleogene shallow-water limestones. The number of magmatic, volcanic and metamorphic clasts in these conglomerates was relatively low. They were probably supplied with material derived from the Marmarosh Massif and its western prolongation, now buried beneath the Central Western Carpathians.

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