Geological Quarterly, 2012, **56** (3): 411–440
DOI: http://dx.doi.org/10.7306/gq.1031

Cretaceous (Aptian/Albian–?Cenomanian) age of "black flysch" and adjacent deposits of the Grajcarek thrust-sheets in the Małe Pieniny Mts. (Pieniny Klippen Belt, Polish Outer Carpathians)

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Oszczypko N., Olszewska B. and Malata E. (2012) – Cretaceous (Aptian/Albian–?Cenomanian) age of "black flysch"and adjacent deposits of the Grajcarek thrust-sheets in the Małe Pieniny Mts. (Pieniny Klippen Belt, Polish Outer Carpathians). Geol. Quart., **56** (3): 411–440, doi: 10.7306/gq.1031

Several sections record the relation between the "black flysch" and Upper Cretaceous red shales in the Grajcarek thrust-sheets. In all the sections studied the "black flysch" appears in the core of imbricated folds or thrust-sheets, whereas the limbs are composed of Upper Cretaceous deposits. The transitional beds between the " black flysch" and the Upper Cretaceous red shales are composed of green and black bituminous shales, green and red radiolarites and cherty limestones. Biostratigraphical investigations have revealed a similar type and sequence of microfauna assemblages in all the sections studied and significant redeposition of Jurassic calcareous benthic foraminifera, calcareous nannoplankton, molluscs, sponge spicules and crinoid elements. The Cretaceous age (Aptian/Albian–?Cenomanian) of the "black flysch" is shown by the presence of agglutinated foraminifera and microfacies data. These deposits are underlain by a Kimmeridgian–Aptian radiolarite/limestone condensed succession and overlain by Turonian–Campanian hemipelagic red shales and Maastrichtian/Lower Paleocene conglomerates and thick-bedded silicilastic turbidites of the Jarmuta Formation. Such a sequence of deposits is typical of the Outer Carpathian basins and records the global Mid/Late Cretaceous phenomena in the world ocean, followed by the Cretaceous Oceanic Red Beds.

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Key words: "black flysch", Cretaceous, foraminifera, Pieniny Klippen Belt.

INTRODUCTION

The Pieniny Klippen Belt (PKB) is the suture zone which separates Central Carpathian Paleogene Basin from the Magura Nappe (Outer Western Carpathians; Fig. 1). The PKB successions are build up of Lower/Middle Jurassic to Upper Cretaceous pelagic and flysch deposits (Birkenmajer, 1977, 1986).

In the Małe Pieniny Mts., the main Paleogene body of the Magura Nappe and PKB is separated by a narrow, strongly deformed peri-PKB Zone, known as the Grajcarek Unit (Birkenmajer, 1977, 1979, 1986) or the Grajcarek thrust-sheets (Oszczypko *et al.*, 2010). This tectonic unit has been recently distinghuished in Eastern Slovakia, as the Fakľovka (Fig. 1B; Oszczypko *et al.*, 2010) or the Šariš Unit (Plašienka and Mikuš, 2010). The Grajcarek thrust-sheets succession is composed of Jurassic, Cretaceous and Paleocene pelagic and flysch deposits belonging to the Magura succession (Birkenmajer, 1977, 1986). According to this concept, the Laramian Grajcarek Unit was thrust back over the PKB, and finally overstepped by the Late Paleocene to Early Eocene "autochthonous Magura Paleogene" as a lateral extension of the Magura Basin (see also Birkenmajer and Oszczypko, 1989). The stratigraphy of the Jurassic and Lower Cretaceous deposits of the Grajcarek succession has been a subject of long-lasting controversy. Recently, the authors critically re-examined, with respect to geology and biostratratigraphy, all major sections of the Jurassic–Cretaceous deposits in the Małe Pieniny Mts., with special emphasis on the Grajcarek succession. In our opinion the results of the studies may contribute to a solution of the contradictions on the age of the "black flysch" deposits, which is important for better understanding of the evolution of the Magura and PKB basins.

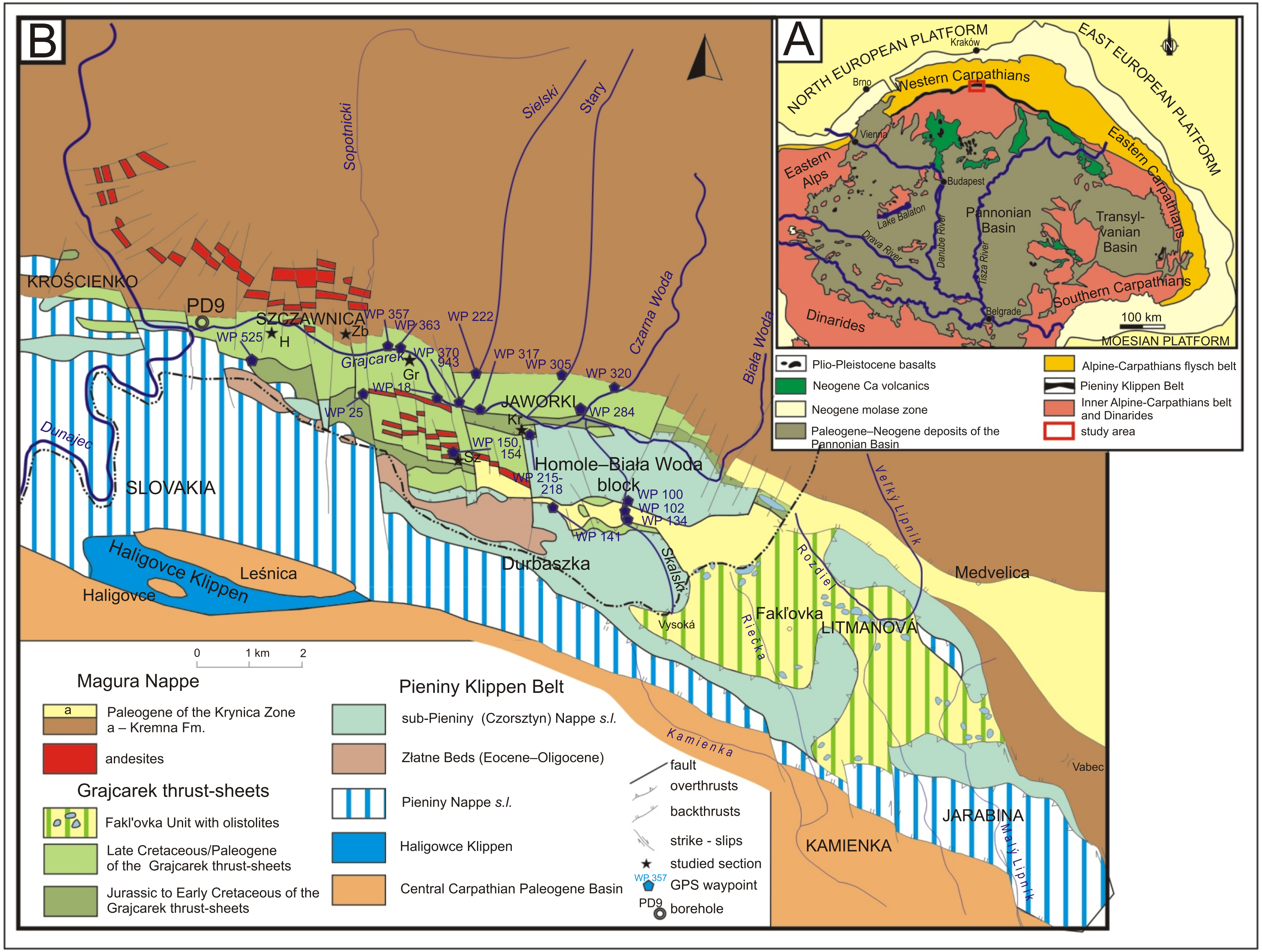

Fig. 1A – position of the area studied in the Alpine-Carpathian and Pannonian realm;
B – geological sketch – map of the of the Małe Pieniny Mts. and Ľubovnianska Vrchovina (based on Oszczypko *et al.*, 2010, supplemented)

Sections studied: H – Hulina, Kr – Krupianka, Sz – Sztolnia, Zb – Szczawnica-Zabaniszcze and dispersed points of sampling, signed by GPS way points (WP)

PREVIOUS WORKS

Horwitz (1929) distinguished, in the PKB, black shales with intercalations of thin- to thick-bedded muscovitic sandstones (“Black Cretaceous”) of Barremian to Albian age, overlain by the Senonian “Red Cretaceous” shales. Subsequently, Horwitz (1933) revised his former opinion and assigned the black shales to the Middle Jurassic. In Birkenmajer’s (1960) early stratigraphical scheme of the PKB these beds were called the “Flysch Aalenian”. Sikora (1962) documented that the beds assigned to the “Flysch Aalenian”, occurring in the Sztolnia Stream near Szczawnica, belong to the Cretaceous, and pass upwards into the Cenomanian black/green shales and Turonian red shales (present Malinowa Formation). Later, Sikora (1971*a*) subdivided the “Flysch Aalenian” in two Cenomanian lithostratigraphic units: the Sztolnia and the Sprzycne beds. This idea was rejected by Birkenmajer (1963) and Birkenmajer and Pazdro (1968). They argued that the microfauna, ostracods, and pelecypods from the shales clearly indicated a Middle Jurassic age, whereas the Cretaceous planktonic and agglutinated foraminifera reported by Sikora (1962) were the result of contamination. Książkiewicz (1977) shared Sikora’s (1962, 1971*a*) point of view and added a few other geological arguments in favour of this opinion. The same point of view was expresed by Golonka and Rączkowski (1984*a*, *b*) in the *Geological Map of Poland* (Piwniczna Sheet).

Birkenmajer (1977) included the “black flysch” into new formal lithostratigraphic units with different names and ages: the Szlachtowa (Toarcian–Aalenian) and Opaleniec (Bajocian) formations. Simultaneously, the Wronine (Lower Albian) and Hulina (Albian–Middle Cenomanian) formations have been established at the base of the Malinowa Shale Formation (Upper Cenomanian–Campanian). A detailed lithological and sedimentological description of the Szlachtowa Formation was given by Krawczyk and Słomka (1986).

The lithotype of the Wronine Beds was described by Birkenmajer and Pazdro (1963). Sikora (1971*a*, *b*) concluded that the name “Wronine Beds” should be used only for the black shales underlain by cherty limestones and overlain by the “black flysch” of the Sztolnia Beds (e.g., Zabaniszcze section). Several years later Birkenmajer (1977) also stated that the Wronine Fm. is very difficult to distinguish from the Opaleniec Fm. (Bajocian), without fossils. In fact, the names of these stratigraphic units have been used interchangeably (Birkenmajer and Pazdro, 1963, 1968; see also Birkenmajer and Gedl, 2007).

In 1967–1969, at the northern boundary of PKB at Szczawnica (Fig.1B), a 1200 m deep borehole, PD9, was drilled. In this borehole a new lithostratigraphic unit – the Bryjarka Fm. (Hauterivian–Albian–Cenomanian), at least 190 m-thick (Fig. 2), was described between the Szlachtowa and Malinowa formations (Birkenmajer *et al.*, 1979). The Bryjarka Fm. has never been included in Birkenmajer’s (1986, 2001) stratigraphical schemes.

Discussion over the “black flysch” stratigraphy was renewed after publication of Oszczypko *et al*. (2004), which presented the new data from the Slovak and Polish sectors of the PKB on the Albian–Cenomanian age of the “black flysch”, and the Cenomanian to Campanian age of the overlying green and red shales, recpectively. The concept of Oszczypko *et al*. (2004) was rejected by Birkenmajer and Gedl (2004, 2007) and Birkenmajer *et al*. (2008), who repeated their previous biostratigraphical arguments favouring Jurassic ages for these formations, and repeating the “contamination” provenance of the Cretaceous pelagic and agglutinated foraminifera of these beds (see also discussion in Gedl, 2008*c*; Oszczypko *et al*., 2008; Malata and Oszczypko, 2010).

Recently Plašienka *et al*. (2012), between Jarabina and Litmanová (East Slovakia, Fig. 1B), drilled, beneath the Czorsztyn Nappe, three thrust-sheets of the Grajcarek Unit (Šariš Unit, according to Plašienka *et al*., 2012). These thrust-sheets are composed of red shales of the Malinowa Fm. (Cenomanian–Santonian) underlain by black shales with intercalations of micaceous sandstones (“black flysch” of Upper Albian age). New data on the black flysch in Poland and East Slovakia are given by Barski *et al*. (2012). These authors proposed, using organic dinocysts, a Bajocian age for the Szlachtowa Formation. However, these authors did not exclude the possibility of an occurrence of similar deposits of Early Cretaceous age in the PKB.

The type section of the Hulina Formation was described on the southern slope of Hulina Hill (Fig. 1B). Interpretation of the Hulina section changed after dinocyst determinations (Birkenmajer and Gedl, 2007; Gedl, 2007). According to this new interpretation the thickness of the Hulina and Wronine formations in this section were considerably reduced and replaced by Jurassic formations: Opaleniec (Bajocian) and Sokolica Radiolarite (former the Middle Albian Groń Radiolarite Member of the Hulina Formation, see Birkenmajer, 1977, and his later papers). The history of controversy regarding the age of the “ black flysch” as well as of the Wronine and Hulina formations is shown in Table 1.

Small exposures of deposits similar to the “black flysch” were found by Nemčok (1990) and Oszczypko *et al*. (2004) near Údol near Stará Ľubovňa in Ľubovnianska Vrchovina, east of the Małe Pieniny Mts.

GEOLOGICAL SETTING

In the Małe Pieniny Mts. the “black flysch”deposits of the Grajcarek thrust-sheets occur both at the front of and inside the PKB (Krawczyk and Słomka, 1968; Jurewicz, 1987, 1997; Oszczypko *et al*., 2010). At the front of the PKB these deposits occur mainly south and south-east of the town of Szczawnica (Fig. 1B), on the southern slope of Hulina Hill, and in the Głęboki and Klimontowski creeks (WP 525, WP 25; Figs. 1B and 3). Towards the east, exposures of the “black flysch” are known on the northern slope of Jarmuta Mt. (WP 18; Fig. 1B), as well as in the Sztolnia and Krupianka Creek valleys (WP 215; Fig. 1B). To the east of the village of Jaworki “black flysch” occurs in a narrow, discontinuous belt, at the front of the PKB, up to the Polish–Slovak boundary. South-east of the Homole block, “black flysch” occurs in tectonic windows of the PKB (see Golonka and Rączkowski, 1981; Jurewicz, 1997) wedged between the klippen units and the “autochthonous Magura Paleogene” (Oszczypko *et al*., 2010; WP 100, 102, 134, 141; Fig. 1B).

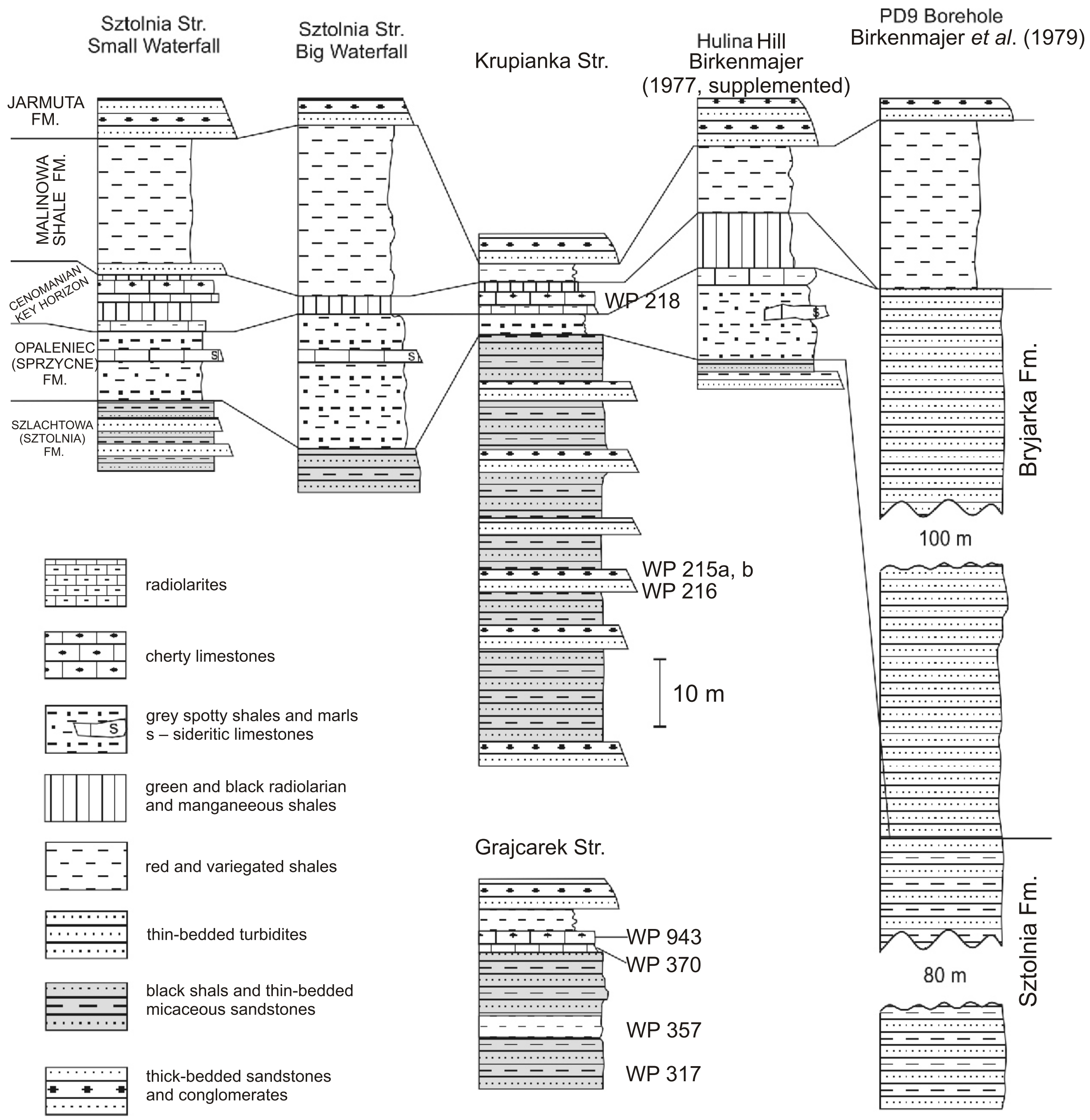

Fig. 2. Lithostratigraphic logs of the sections studied

Hulina section after Birkenmajer (1977)

In all sections studied, the "black flysch" appears in the core of imbricated folds and/or thrust sheets, whereas the limbs of the folds are composed of the Malinowa (Turonian–Campanian) and Jarmuta (Maastrichtian–Paleocene) formations. Locally the Jarmuta Formation directly overlies the "black flysch". From our investigations it appears that the lower boundary of the "black flysch" is everywhere tectonic. The only place where the stratigraphic base of "black flysch" can be preserved is in the section of Late Jurassic–Early Cretaceous rocks on the left bank of Grajcarek Stream at Szczawnica-Zabaniszcze (Zb on the Fig. 1B; *cf.* Sikora, 1971*a*, *b*). The total thickness of the "black flysch" is at least 220 m (Birkenmajer, 1977, see also Birkenmajer *et al*., 2008). In the borehole PD9, at Szczawnica (Figs. 1B and 2; see Birkenmajer *et al*., 1979) the tectonic base of these strata was penetrated at a depth of 855 m. In this borehole the incomplete thickness of the "black flysch" was about 310 m, 120 m and 190 m of the Szlachtowa and Bryjarka formations, respectively. The review of the history of "black flysch" studies implies that the the lithostratigraphic nomenclature proposed by

Table 1

Review of the previous studies on the “black flysch” in the Pieniny Klippen Belt

<table>
<tr><th>SECTION
FORMATION</th><th>SZTOLNIA A</th><th>SZTOLNIA B</th><th colspan="2">HULINA</th></tr>
<tr><td>MALINOWA</td><td>Variegated shales Turonian–Senonian (Sikora, 1962, 1971b); Malinowa Fm. Cenomanian–Campanian (Birkenmajer and Myczyński, 1977)</td><td>Variegated shales Turonian–Senonian (Sikora, 1962, 1971b); Malinowa Fm. Cenomanian–Campanian (Birkenmajer and Myczyński, 1977)</td><td colspan="2">Malinowa Fm. Cenomanian–Campanian (Birkenmajer, 1977; Birkenmajer and Gedl, 2007)</td></tr>
<tr><td>SPOTTED LIMESTONES</td><td>Albian–Cenomanian (Oszczypko et al., 2004); Pieniny Limestone Fm. Tithonian–Barremian (Birkenmajer and Gedl, 2004), Hauterivian–Barremian (Gedl, 2007)</td><td></td><td rowspan="3">Hulina Formation (Groń Rad. Mb.– Albian, Uboc Sh. Mb. Upper Albian–Lower Cenomanian; Birkenmajer, 1977, 2001)</td><td>Hulina Formation (Birkenmajer and Gedl, 2007)
Opaleniec Formation (Birkenmajer and Gedl, 2007)</td></tr>
<tr><td>RADIOLARITES</td><td></td><td></td><td>Sokolica Formation (Birkenmajer and Gedl, 2007)</td></tr>
<tr><td>RADIOLARITE SHALES</td><td>Cenomanian Key Horizon (Sikora,1971b); Hulina Fm. Albian–Cenomanian (Birkenmajer, 1977)</td><td>Cenomanian Key Horizon (Sikora,1971b); Hulina Fm. Albian–Cenomanian (Birkenmajer, 1977)</td><td rowspan="2">Opaleniec Formation (Birkenmajer and Gedl, 2007)</td></tr>
<tr><td rowspan="2">OPALENIEC</td><td rowspan="2">Sztolnia Beds, Lower Cenomanian (Sikora, 1962); Sprzycne Beds, Lower Cenomanian (Sikora, 1971b); Aalenian flysch, (Birkenmajer and Pazdro, 1968); Toarcian–Aalenian (Birkenmajer and Gedl, 2004; Birkenmajer et al., 2008); Upper Toarcian–Upper Bajocian (Gedl, 2008); Black Flysch (Szlachtowa Formation) – Albian–Cenomanian (Oszczypko et al., 2004)</td><td rowspan="2">Sztolnia Beds, Lower Cenomanian (Sikora, 1962); Wronine Beds, Lower Cretaceous (Birkenmajer and Pazdro, 1968); Sprzycne Beds, Cenomanian (Sikora, 1971b); Opaleniec Formation, Lower Bajocian (Birkenmajer, 1977; Birkenmajer and Myczyński, 1977); Middle Cenomanian–Turonian (Oszczypko et al., 2004); Bajocian–Bathonian (Gedl, 2008)</td><td rowspan="2">Wronine Formation (?Lower Albian, Birkenmajer, 1977, 2001)</td></tr>
<tr><td>Wronine Formation (?Lower Albian, Birkenmajer, 1977, 2001)</td></tr>
<tr><td>SZLACHTOWA</td><td>Sztolnia Beds, Lower Cenomanian (Sikora, 1962, 1971b); Aalenian flysch (Birkenmajer and Pazdro, 1968); Szlachtowa Formation (?Upper Toarcian–Lower Aalenian, Birkenmajer, 1977); Toarcian–Aalenian (Birkenmajer and Gedl, 2004); Black Flysch (Szlachtowa Formation, Albian–Cenomanian, Oszczypko et al., 2004)</td><td>Aalenian flysch (Birkenmajer and Pazdro, 1968); Sztolnia Beds, Lower Cenomanian (Sikora, 1971b); Szlachtowa Formation (?Upper Toarcian–Lower Aalenian, Birkenmajer, 1977); Toarcian–Aalenian (Birkenmajer and Gedl, 2004); Black Flysch (Szlachtowa Formation, Albian–Cenomanian Oszczypko et al., 2004)</td><td colspan="2">Szlachtowa Formation Toarcian–Aalenian (Birkenmajer, 1977, 2001; Birkenmajer and Gedl, 2007)</td></tr>
</table>

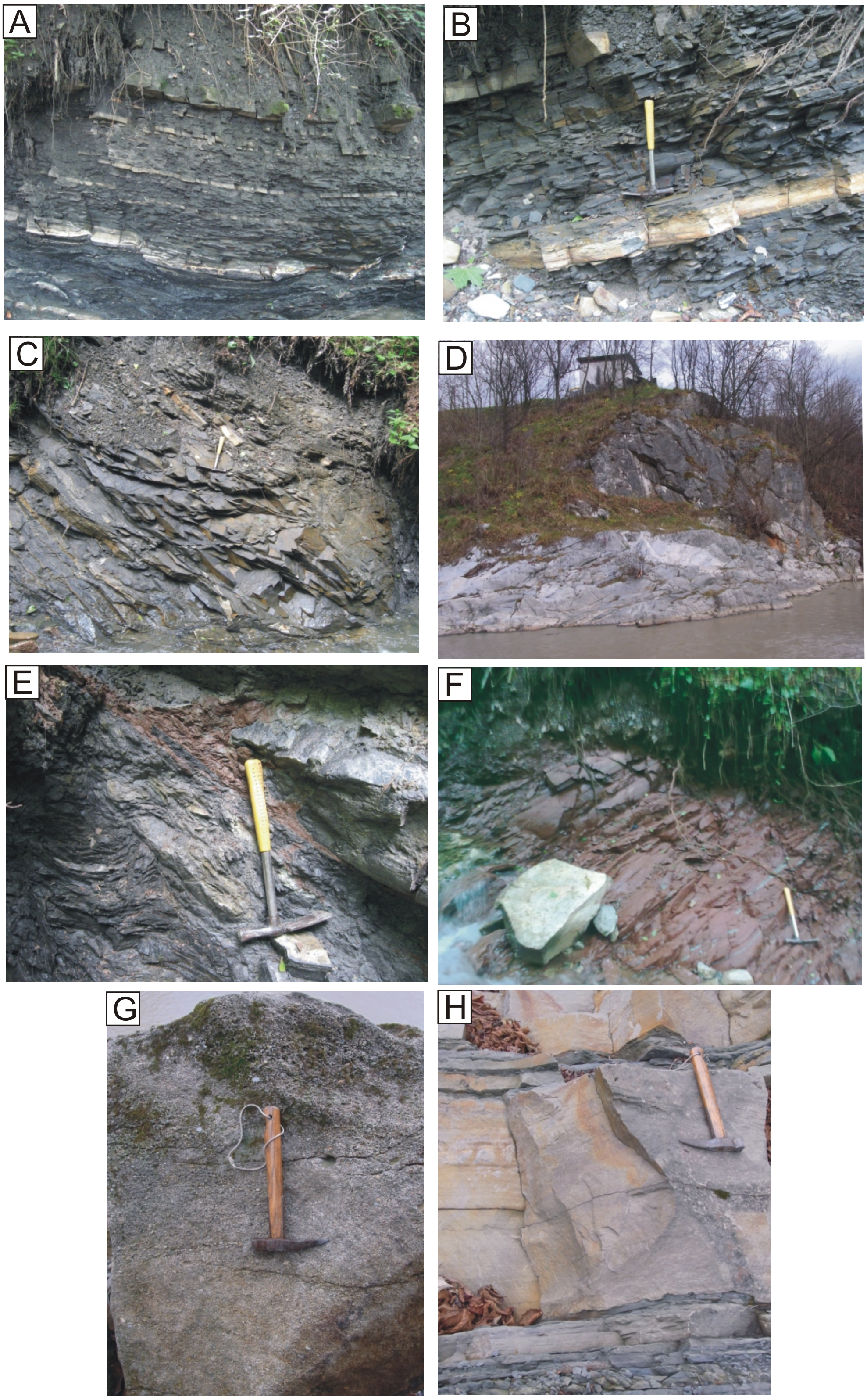

Fig. 3. Main lithological varieties of the Grajcarek thrust-sheets deposits in the Małe Pieniny Mts.

A – shaly facies of the Szlachtowa Fm., lower section of the Sztolnia Stream; **B** – thin- to medium-bedded muscovitic sandstones with intercalations of black calcareous mudstone, upper part of the Szlachowa Fm., lower section of the Sztolnia Stream; **C** – massive grey green spotted mudstones of the Opaleniec Fm., lower section of the Sztolnia Stream; **D** – klippen of cherty limestones, right bank of the Grajcarek at Szlachtowa; **E** – brecciated red shales of the Malinowa Fm. and "black flysch" – the fault zone in the lower section of the Sztolnia Stream; **F** – red shales of the Malinowa Fm., middle section of the Sztolnia Stream; **G** – fine conglomerates of the Jarmuta Fm., left bank of the Grajcarek Stream, Szczawnica–Malinów; **H** – thick-bedded sandstones of the Jarmuta Fm., the same location

Sikora (1962, 1971*a*, *b*) should have priority. On the other hand, the formal lithostratigraphic units of Birkenmajer (1977 and later papers) have been used in the Carpathian geological literature for several decades.

The Szlachtowa Formation is a typical "black flysch" composed of thin- to thick-bedded turbiditic sandstone with intercalations of black and dark grey marly mudstone and shale with muscovite flakes (Fig. 3A, B). Additionally, intercalations of siderite and thin-laminated coal layers have been also observed (see Krawczyk and Słomka, l986). The thin- to medium-bedded, micaceous sandstones are fine- to coarse-grained, dark grey and bluish coloured and locally they contain a substantial amount of crinoidal fragments and clasts of grey and yellow limestone (see Głuchowski *et al*., 1983). The sandstones are calcareous and often show parallel lamination. In the Krupianka and Głęboki streams the upper part of the formation contains intercalations of thick- and very thick-bedded sandstone and coarse- and very coarse-grained sandstone, rich in carbonatic clasts (Krawczyk and Słomka, 1986). These sandstones often display parallel lamination (Tb – turbidites). Locally the sandstones are very rich in crinoidal grains. The Szlachtowa Fm., at least 100 m thick (Fig. 2), passes upwards into a 10 to 16 m-thick packed of light grey spotted shales and marls with pyrite concretions and sideritic limestone intercalations belonging to the Opaleniec Formation (Fig. 3C). The Opaleniec Formation is best exposed in the Sztolnia and Krupianka creeks. In the other setions it is difficult to distinguish these strata. In the middle section of the Grajcarek Stream (WP 357; Fig. 1B) the Szlachtowa-type lithofacies shows intercalations of red shale. The red shales within the Szlachowa Formation were also described by Krawczyk and Słomka (1986).

At the base of the Upper Cretaceous red and variegated shales, Sikora (1962, 1971*b*) distinguished a "Cenomanian Key Horizon" (CKH), which more or less corresponds with the Hulina Fm. (see Birkenmajer, 1977). In the sections studied by us these beds (CKH) are represented by 1–3 m of green, non-calcareous shales with manganeous coatings and thin intercalations of black shale (Fig. 2). In several sections between the "black flysch" and the Upper Cretaceous red shales of the Malinowa Formation there are layers of red and green radiolarites followed by cherty limestones and/or spotted (black) limestones/green radiolarites (Figs. 2 and 3D; see also Horwitz, 1963). These limestones and radiolarites were previously regarded by Birkenmajer (1977, 1979 and later papers) as tectonic blocks derived from the Branisko Unit.

Higher up in the sections studied the red and variegated shales of the Malinowa Formation occur. Its lower boundary is sharp, against the CKH, manifested by the first appearance of red shales, whereas the upper boundary with the Jarmuta Fm. is transitional. The Malinowa Formation is composed mainly of non-calcareous cherry-red and green argillaceous shales (Fig. 3E), but in the southern thrust sheets of the Grajcarek succession the variegated shales are locally replaced by massive cherry-red marls.

In the sections studied, the thickness of the Malinowa Formation is up to 25 to 30 m and only a part of the formation is exposed. On the southern slope of Jarmuta Mt., the red shales between the Jarmuta and the Opaleniec formations are only a few metres thick and in some places they disappear. The reason of this phenomenon is not clear, but it can be both of tectonic and/or sedimentary nature (submarine erosion). At the mouth of the Sielski Brook to the Grajcarek Stream (WP 370; Fig. 1B) and along the lower reaches of Czarna Woda Brook (WP 284; Fig. 1B) the basal portion of the Jarmuta Fm. contains debris flow paraconglomerates with clasts of red shale and of Lower/Middle Cretaceous limestone and radiolarite. In the northern thrust-sheets in the Sielski and Stary brooks the variegated shales of the Malinowa Formation contain thick intercalations of thick- and very thick-bedded sandstones, up to 6 m-thick. The measured thickness of the Malinowa Fm., in these sections, is at least 180 m. These massive sandstones, different from the typical Jarmuta sandstones, are mainly fine- to medium-grained with non-calcareous cement. This type of thick-bedded sandstones, wedged between variegated shales, probably occurs also in the middle section of the Sztolnia Stream (WP 150, 154; Fig 1B), and reaches up to 350 m in thickness. In some publications (Birkenmajer and Pazdro, 1968; Birkenmajer, 1979; Golonka and Rączkowski, 1984*a*, *b*) these sandstones were described as belonging both to the Jarmuta and to the Eocene Magura Sandstones. According to Birkenmajer (1977, 1979; Birkenmajer and Oszczypko, 1989). The Malinowa Fm. is of Late Cenomanian–Campanian in age. The typical Jarmuta Fm. is developed as thick-bedded turbidites (Fig. 3G, H) with subordinate occurrences of grey marly shale. The sandstones, 0.5–5 m-thick, are fine- to very coarse-grained, with calcareous cement, bluish and yellowish when weathered. In the Jarmuta Mt. syncline the basal part of the Jarmuta sandstones contains intercalations of red shale (see also Birkenmajer, 1979). In the Stary and Czarna Woda Stream sections (WP 305, 320 in the Fig. 1B) the upper part of the Jarmuta Formation (Middle Paleocene, NP5 zone, Birkenmajer *et al*., 1987) contains thick packets of exotic rocks. These rocks are represented by frequent intercalations of thick-bedded granule to cobble paraconglomerates (pebbly mudstones and sedimentary breccia), rich in carbonate clasts derived from the PKB as well as clasts of red shale of the Malinowa Fm. According to Birkenmajer and Wieser (1990) the Jarmuta conglomerates from the Biała Woda section are dominated by volcanic rocks and carbonates as well as sedimentary clastic rocks (see Krobicki and Olszewska, 2005). In the Małe Pieniny Mts. the thickness of the Jarmuta Fm. varies from several dozen metres in the southern part to 400 m in the northern thrust sheets. The palaeocurrent measurements show supply of clastic material from the SE. In the Szczawnica and Biała Woda sections the heavy mineral assemblages of the Jarmuta Fm. contain relatively high contents of chromian spinels of ophiolite provenance (Oszczypko and Salata, 2005).

SECTIONS STUDIED

SZCZAWNICA-ZABANISZCZE

Unique exposures are located in Szczawnica (Figs. 1B and 4) at the left bank of the Grajcarek Stream and the small left confluence of the Grajcarek Stream (Fig. 4). The *ca*. 20 metres long exposure (Fig. 4B; see Nowak, 1971; Birkenmajer, 1979;

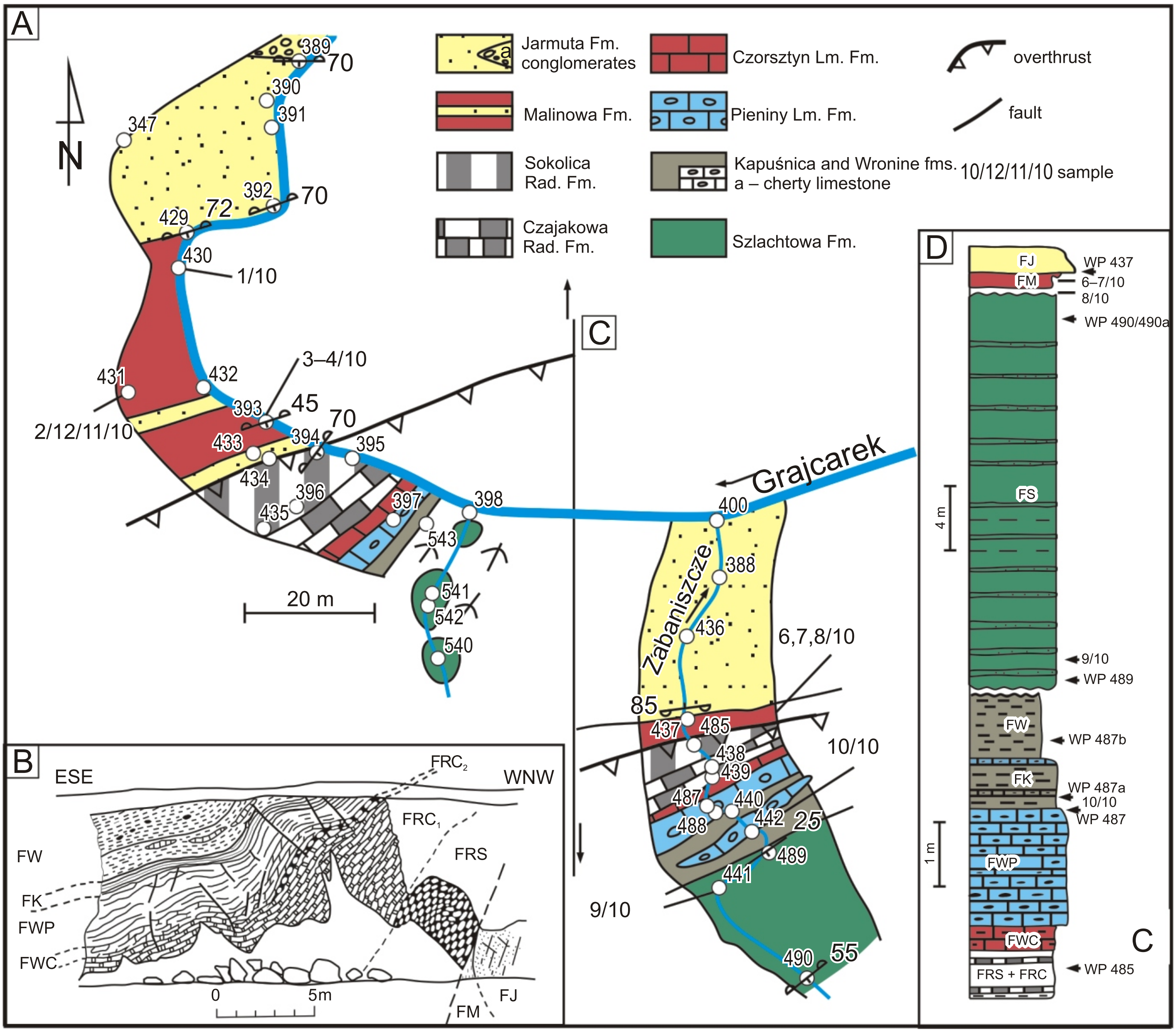

Fig. 4. Geological position of the klippen at Szczawnica-Zabaniszcze

A – geological sketch-map of the left bank of the Grajcarek Stream at the outlet of the Zabaniszcze Stream; **B** – the left bank section according to Birkenmajer (1979); **C** – geological sketch-map of the outlet of the Zabaniszcze Stream; **D** – lithostratigraphic log and location of samples of the Zabaniszcze Stream outlet section; abrevations (see Birkenmajer, 1979; Gedl, 2007): FRS – Sokolica Radiolarite Formation (?Bajocian–?Oxfordian); FRC – Czajakowa Radiolarite Formation; FRC_1 – Czajakowa Radiolarite Formation, Podmajerz Radiolarite Member (Oxfordian); FRC_2 – Czajakowa Radiolarite Formation, Buwald Radiolarite Member (Oxfordian); FWC – Czorsztyn Limestone Formation, Palenica Marlstone Member (Kimmeridgian–Tithonian); FWP – Pieniny Limestone Formation (Tithonian–Barremian); FK – Kapuśnica Formation – spotted marls (Aptian–Albian); FW – Wronine Formation (1 m-thick, black calcareous shales of Albian age); FS – Szlachtowa Fm.; this sequence overthrusts the Late Cretaceous variegated shales of the Malinowa Formation (FM) and the Jarmuta type sandstones (FJ)

Gedl, 2007) shows Jurassic to Lower Cretaceous, strongly condensed, pre-flysch deposits of the Grajcarek thrust-sheets. In this section several formations have been distinguished by Birkenmajer (1979; Fig. 4B).

The next exposure is located along the banks and bed-rock of the Zabaniszcze Stream, left-lateral confluence of the Grajcarek Stream (Fig. 4C, D). This profile was studied by Sikora (1971*b*), while the microfacies were described by Nowak (1971). The sequence is as follows (see Sikora, 1971*b*): 0.95 m of of manganeous, green and red radiolarites (FRS and FCR, see section A), 0.45 m of red Aptychus shales and variegated limestones (FWC), 1.75 m of pelitic, spotted and cherty limestones (FWP), 0.80 m of dark marls and spotted limestones, black and green silicified shales, spotted limestones (FK), 0.75 m of green greyish, manganeous shales and marls (FW); and 0.15m of dark brown shales as transition beds to flysch deposits of the Szlachtowa Fm., a few dozen metres thick. According to our data (Fig. 4C, D) this section displays *ca*. 16 m of subvertically dipping Upper Jurassic to Lower Cretaceous pelagic deposits.

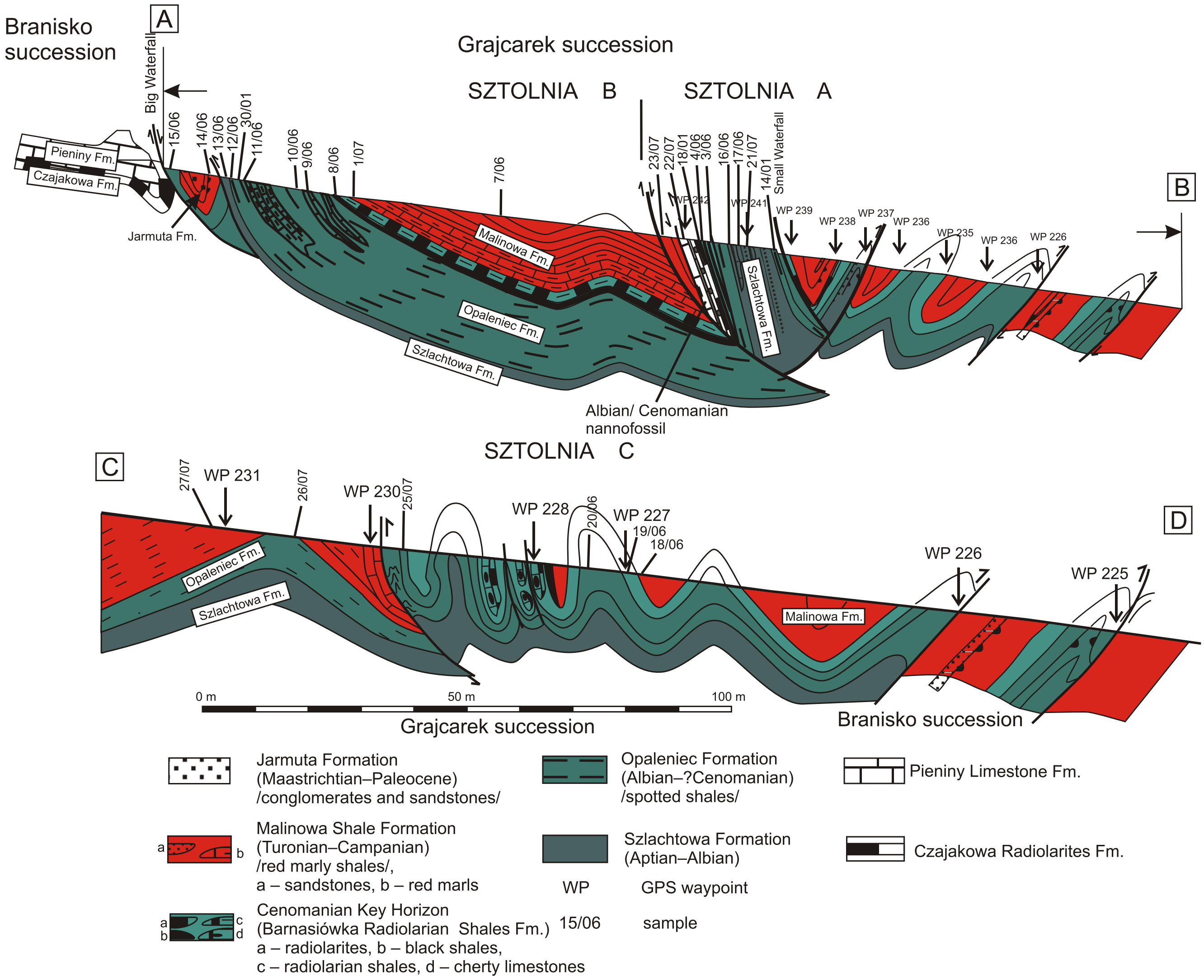

Fig. 5. Geological cross-section; upper section of the Sztolnia Stream with location of samples (sections A–C; for location see Fig. 1B and Table 2)

SZTOLNIA STREAM SECTION

The Sztolnia section displays intensely folded Lower to Upper Cretaceous deposits of the Grajcarek thrust-sheets, mainly clayey deposits squeezed between more rigid rocks of the Jarmuta Formation (Maastrichtian–Paleocene) in the north and the Branisko Klippen in the south (Figs. 1B and 5). The exposures in the upper course of the Sztolnia Stream comprise two sections (A and B) previously studied by Sikora (1962, 1971*b*), Birkenmajer and Pazdro (1968), Książkiewicz (1977), Birkenmajer and Myczyński (1977), as well as by Oszczypko *et al.* (2004), Birkenmajer and Gedl (2004) and Birkenmajer *et al.* (2008).

As a result of deep erosion during the last forty years, these sections significantly differ in detail from those described both by Sikora (1971*b*) as well as by Birkenmajer and Pazdro (1968), Birkenmajer and Myczyński (1977) and Birkenmajer *et al.* (2008). In addition, section C, located in a left inlet of the Sztolnia Stream (Figs. 5, 6 and 7), has been also a subject of our studies.

Section A (Small Waterfall) up to 22 m-thick is composed of the following lithostratigraphic units (Figs. 5 and 6): 3–4 m of subvertically dipping dark grey marly shales with a few intercalations of micaceous sandstones of the Szlachtowa Fm.; up to 12 m of light grey, massive, marly shale with intercalations of sideritic limestone and pyrite concretions with 1 m of grey greenish, non-calcareous shales at the top – Opaleniec Fm.; Cenomanian Key Horizon (CKH) – 1.0–1.5 m of green radiolarian shales with intercalations of black shale, 5–8 cm of willow green (celadon) shales; 0.1m of pyrite framboids and green radiolarites; 2.0 m of pelitic light grey spotted limestones and marls with several intercalations of bioturbated black shales up to 20 cm thick; 0.25–0.3 m green greyish non-calcareous shales with a few intercalations of black shale; 1 m of red and green shales with intercalations of grey mudstones (Malinowa Shale Formation).

Section B (Large Waterfall; Figs. 5 and 6) is up to 45 m thick: 1–1.5 m of dark grey and black marly shales and mudstones, with intercalations of micaceous sandstone of the Szlachtowa Fm.; 22 m of grey greenish spotted shales with sideritic limestones at the top of the Opaleniec Fm.; 2.0–2.25 m greenish and black shales, partly siliceous with thin intercalations of green radiolarite (CKH); 19 m of red marly shales with

Table 2

Geographical position of way points (WP) cited in this paper

Szlachtowa, Palkowski Stream	WP 25	N 49° 24.366' E 20° 33.328'
Szlachtowa, Grajcarek Stream	WP 357	N 49° 24.697' E 20° 31.339'
Jaworki "upon Homole"	WP 141	N 49° 24.364' E 20° 32.248'
Jaworki, Krupianka Stream	WP 215	N 49° 24.370' E 20° 32.382'
Szczawnica, pod Huliną	WP 562	N 49° 25.268' E 20° 27.850'
Szczawnica-Zabaniszce, Grajcarek Stream	WP 393	N 49° 25.178' E 20° 29.217'
Szczawnica-Zabaniszce, Zabaniszcze Stream	WP 437	N 49° 25.153' E 20° 29.265'
Szczawnica-Zabaniszce, Zabaniszcze Stream	WP 439	N 49° 25.153' E 20° 29.265'
Szczawnica-Zabaniszce, Zabaniszcze Stream	WP 441	N 49° 25.139' E 20° 29.269'
Szczawnica-Zabaniszce, Zabaniszcze Stream	WP 442	N 49° 25.144' E 20° 29.273'
Szczawnica-Zabaniszce, Zabaniszcze Stream	WP 485	N 49° 25.155' E 20° 29.270'
Szczawnica-Zabaniszce, Zabaniszcze Stream	WP 487	N 49° 25.153' E 20° 29.265'
Szczawnica-Zabaniszce, Zabaniszcze Stream	WP 490	N 49° 25.132' E 20° 29.373'
Szlachtowa, Grajcarek Stream	WP 317	N 49° 24.592' E 20° 32.532'
Szlachtowa, inlet of Sielski Stream	WP 370	N 49° 24.647' E 20° 31.447'
Szlachtowa, inlet of Sielski Stream	WP 375	N 49° 24.617' E 20° 31.411'
Szlachtowa, inlet of Sielski Stream	WP 943	N 49° 24.632' E 20° 31.383'
Szlachtowa, Silelski Stream	WP 222	N 49° 24.742' E 20° 31.567'
Szlachtowa, Pod Jarmutą	WP 18	N 49° 24.644' E 20° 31.142'
Jaworki, Skalski Stream	WP 100	N 49° 23.690' E 20° 33.841'
Jaworki, Skalski Stream	WP 102	N 49° 23.628' E 20° 33.802'
Jaworki, Skalski Stream	WP 134	N 49° 23.694' E 20° 33.305'
Jaworki, Sztolnia Stream	WP 150	N 49° 24.278' E 20° 32.167'
Jaworki, Sztolnia Stream	WP 154	N 49° 24.228' E 20° 31.763'
Jaworki, Krupianka Stream	WP 216	N 49° 24.363' E 20° 32.407'
Jaworki, Krupianka Stream	WP 218	N 49° 24.346' E 20° 32.409'
Jaworki, Czarna Woda Stream	WP 284	N 49° 24.546' E 20° 33.388'
Jaworki, Stary Stream	WP 305	N 49° 24.765' E 20° 33.892'
Jaworki, Czarna Woda Stream	WP 320	N 49° 24.666' E 20° 32.654'
Szczawnica, Głęboki Stream	WP 525	N 49° 26.406' E°20 25.137'

intercalation of grey mudstone (Malinowa Shale Fm.). A small exposure of the Jarmuta Formation occurs in the upper part of the section (Fig. 5).

Section C (left tributary of the Sztolnia Stream) dispalys strongly deformed small anticline with the Opaleniec (Sprzycne) Formation and CKH in the cor of fold, and red shales of the Malinowa Fm. on the wings.

KRUPIANKA STREAM SECTION

This section, with a length of approximately 250 m (Fig. 1B), is located in the lower reaches of the Krupianka Stream. This section has been repeatedly described (Birkenmajer and Pazdro, 1968; Birkenmajer, 1977; 1979, see also Gedl, 2008*a*, *b*). The lower part of the section displays black to dark grey marly mudstones with thin- to medium-bedded, calcareous, micaceous sandstones – the Szlachtowa Fm. The upper part of the section displays black shaly flysch with thin-bedded sandstone intercalations (Fig. 8A) and rare sphaerosiderite lenses. Higher up in the section, black flysch passes upwards into thick-bedded (up to 1.5 m-thick) sandstones (WP 215). These sandstones are intercalated (Fig. 8B) with dark grey and black marly shales with thin to medium-bedded, laminated sandstones typical of the Szlachtowa Fm. These type of deposits, up to 60 m-thick, are overlain (WP 217) by *ca*. 2 m grey and greenish spotted marls – the Opaleniec Fm. This horizon is overlain by 2–2.5 m of spotted limestones with green and red radiolarite lenses at the base (Fig. 8C), see also Birkenmajer (1979), Gedl (2008*a*, *b*). The uppermost part of the section studied is composed of a 2 m-thick packet of grey shales and 1 m of red shales (WP 218) of the Malinowa Formation, overthrust by black shales of the Skrzypne Formation (Bajocian) of the Czorsztyn Nappe of the PKB.

HULINA HILL SECTION

The Hulina section, aproximately 40 m long, located on the SW slopes of Hulina Hill (Figs. 1B, 2 and 9), was repeatedly described by Birkenmajer (1977, 2001), Birkenmajer and Gedl (2007) and Gedl (2007). The Hulina section is exposed in the core of a small, asymmetrical anticline. On the reduced southern limb there occur red shales of the Malinowa Fm. and conglomeratic sandstones of the Jarmuta Fm. The following succession of strata may be observed: 2 m of black shales with intercalations of muscovitic sandstone of the Szlachtowa Fm.; 11–12 m of the Opaleniec Fm., represented by black and dark green, mainly non-calcareous, shales with pyrite concretions,

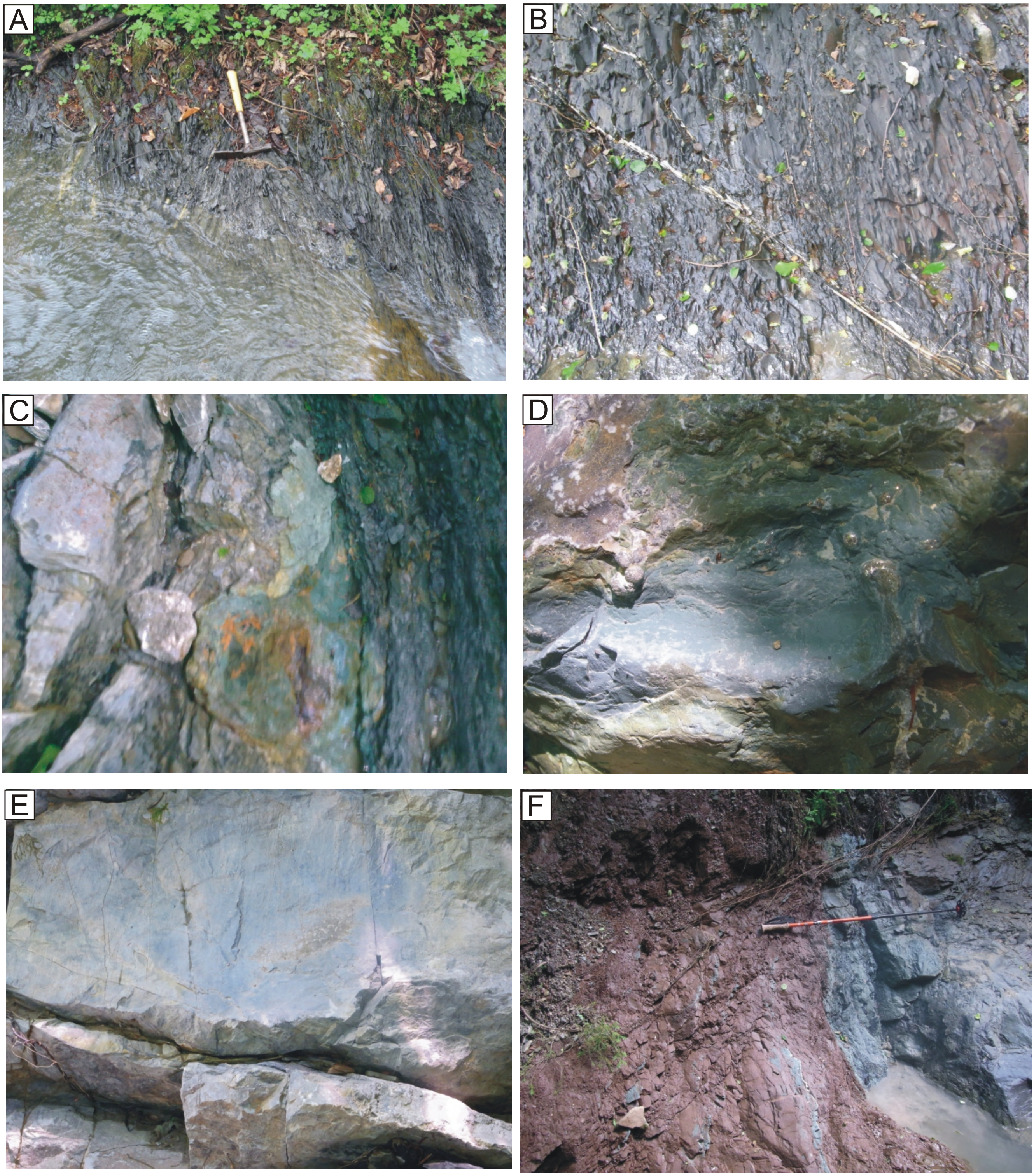

Fig. 6. Typical litofacies of the upper section of the Sztolnia Stream (sections A and B)

A – shaly facies of the uppermost part of the Szlachtowa Fm. (section A); **B** – shaly facies of the uppermost part of the Szlachtowa Fm. (section A); **C** – level of green radiolarites and pyrite framboids at the base of light pelitic spotted limestone (CKH; section A); **D** – light pelitic spotted limestones (section A); **E** – boundary of the massive grey and green mudstones (Opaleniec Fm.) and green and black shales (CKH) with the Malinowa Shale Fm. (section B)

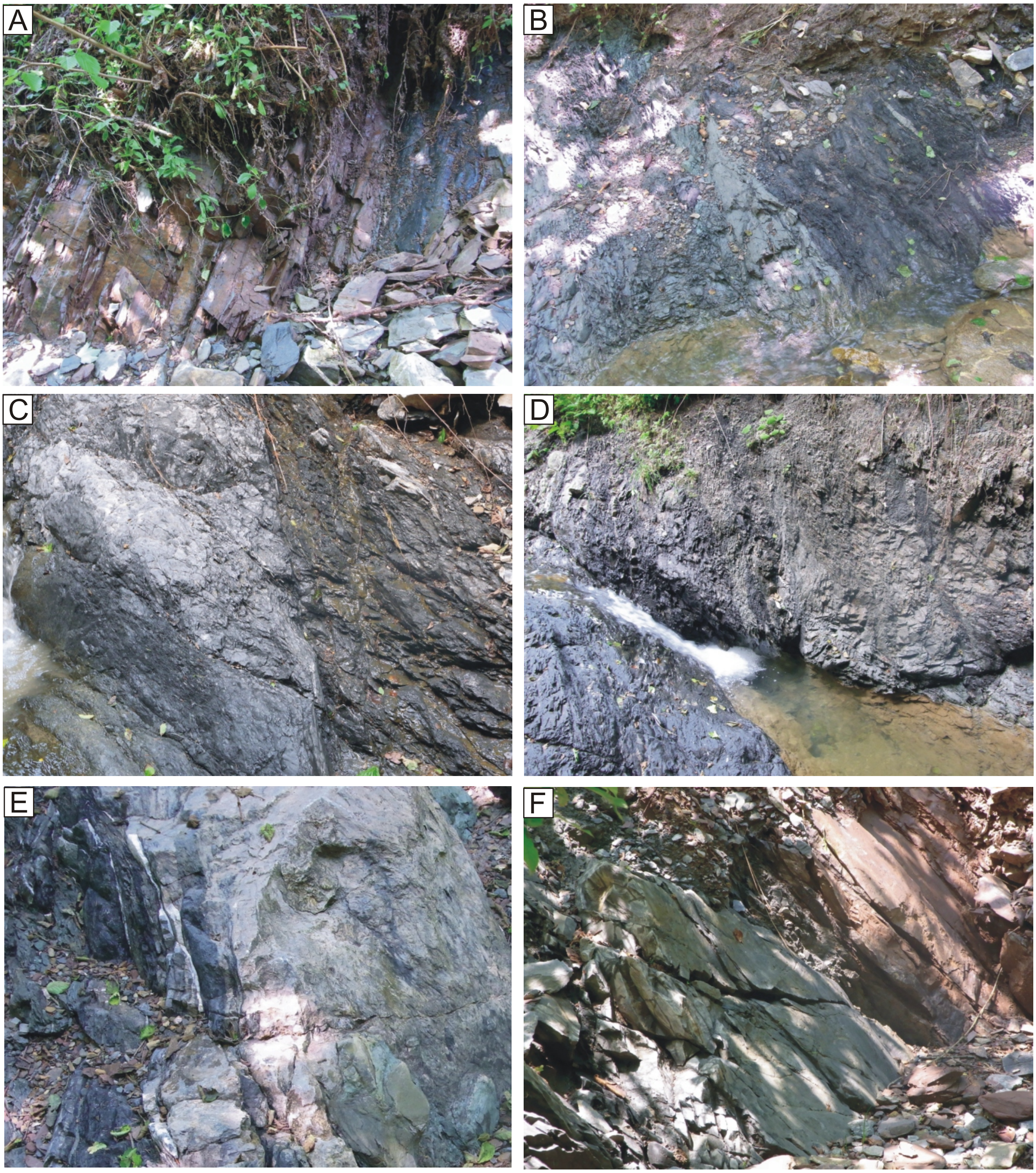

Fig. 7. Typical lithofacies of the left confluence upper section of the Sztolnia Stream (sections C)

A – boundary black shales (CKH) and red shales of the Malinowa Shale Fm. middle section of the Sztolnia Stream, left bank; **B** – black and grey greenish shales CKH, left confluence of Sztolnia Stream; **C**, **D** – black and dark grey massive shale of CKH; **E** – spotted limestones and black shales (CKH); **F** – grey and reddish mudstones of the Malinowa Shale Fm.

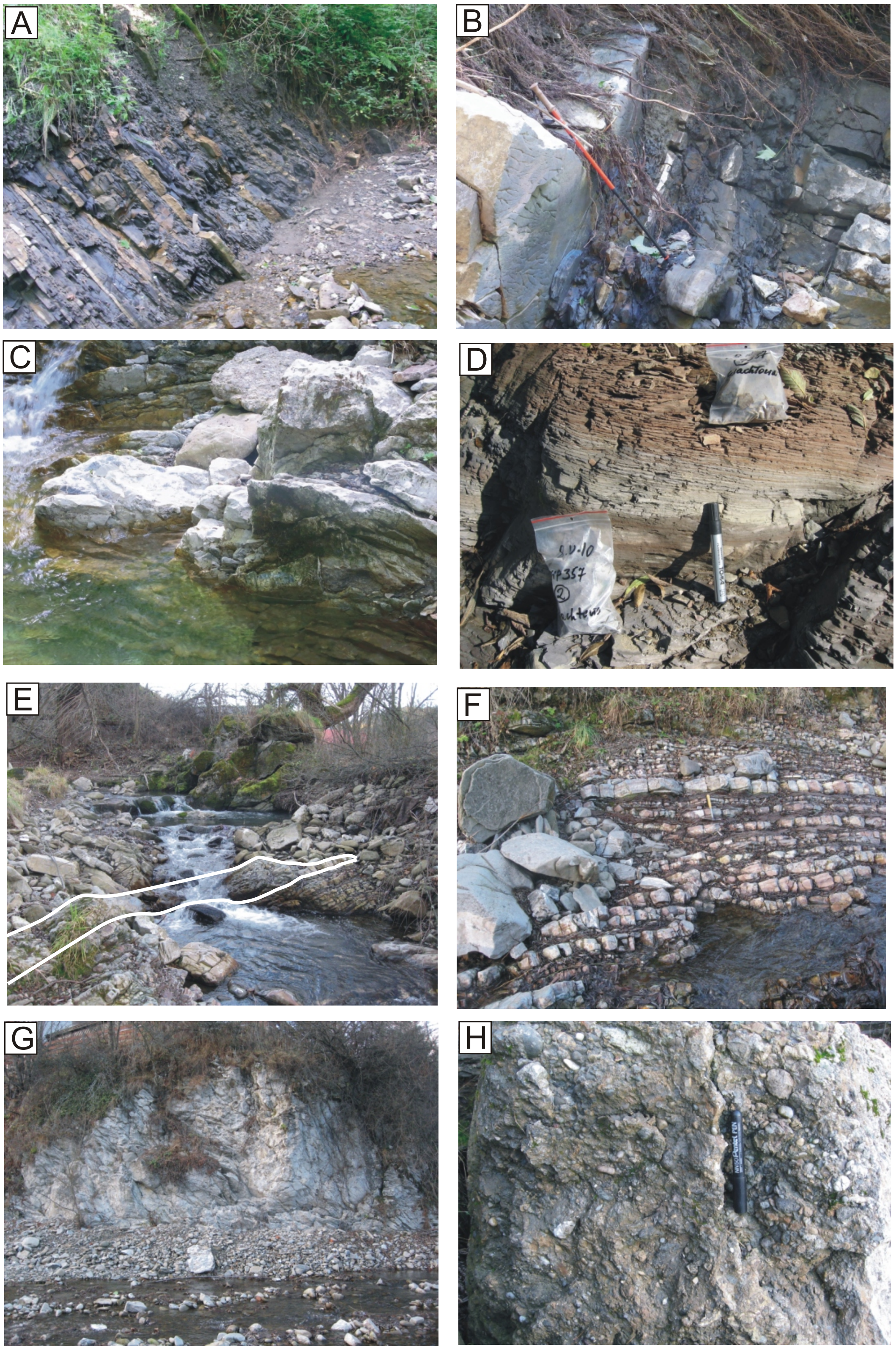

Fig. 8. Typical lithofacies of the Krupianka, Grajcarek and the Sielski Stream sections

A – thin-bedded "black flysch" of the Szlachtowa Fm., lower section of the Krupianka Stream; **B** – thick-bedded micaceous sandstones with intercalations of black shale and mudstone of the upper part of the Szlachtowa Fm. (WP 215); **C** – red and green radiolarites and white pelitic limestones (CKH) at the base of the Malinowa Shale Fm. (Turonian–Campanian), WP 217–218, location as above; **D** – dark grey micaceous mudstones with intercalations of cherry-red mudstones with assemblage of Albian fominifera, uppermost part of the Szlachtowa/Opaleniec formations, right bank of the Grajcarek Stream section at Szlachowa, WP 357; **E** – red and green radiolarites with intercalations of red shale (CKH) at the base of the Jarmuta Fm. (Maastrichtian–Paleocene), the inlet of the Sielski Stream to the Grajcarek Stream at Szlachowa, WP 370–374; **F** – red and green radiolarite with intercalation of red shale; **G** – pelitic limestones; **H** – conglomerates of the Jarmuta Fm. (Maastrichtian–Paleocene), locations as above

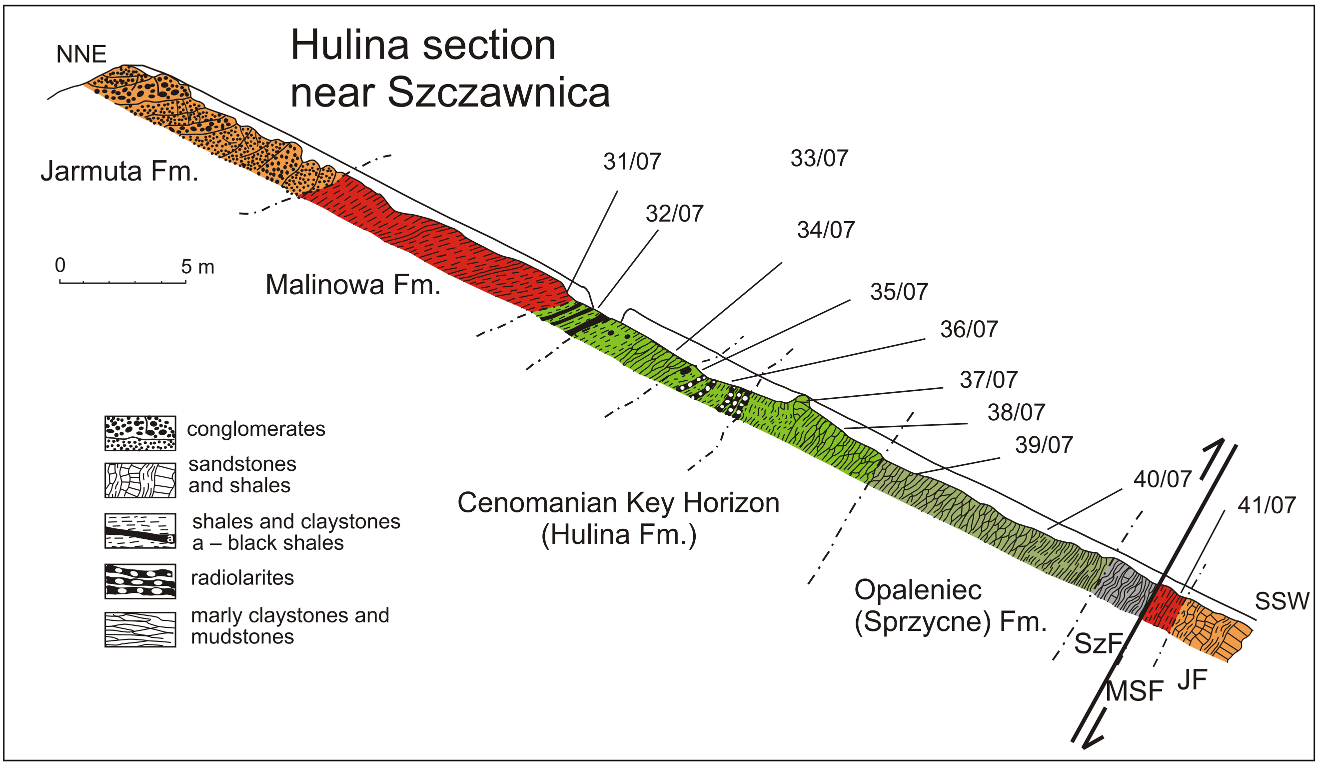

Fig. 9. Cross-section along the SW slope of Hulina Hill (based on Birkenmajer, 1977, reinterpreted)

SzF – Sztolnia Fm., MSF – Malinowa Fm., JF – Jarmuta Fm.

and 50 cm of spotted limestones at the base, *ca*. 15 m of the Cenomanian Key Horizon (see Hulina Formation, Birkenmajer, 1977), which could be correlated also with the Barnasiówka Radiolarian Shale Formation (Bąk *et al*., 2001; Bąk, 2011). The CKH sequence contains *ca*. 3 m of green and black brown non-calcareous shales, with thin intercalations (1–2 cm) of black chert (radiolarite?), and 12 m of grey greenish, celadon and black spotted, shales, locally with manganeous coatings. The Hulina section was sampled by us in 2007 (see Wójcik-Tabol and Oszczypko, 2010, 2012).

GRAJCAREK STREAM SECTIONS AT SZLACHTOWA

In the Grajcarek Stream at Szlachtowa, in the uppermost part of the Szlachtowa Fm., we have found and sampled dark grey mudstones with thin intercalations of cherry-red shale (WP 357; Fig. 8D). At the mouth of the Sielski Stream the black flysch of the Szlachtowa lithofacies is in contact with red and green radiolarites up to 1 m thick, with intercalations of red shale (sample WP 370–375 and WP 943). The radiolarites are overlain by spotted limestones up to 4 m thick, and are visible on the right bank of the Grajcarek Stream (Figs. 1B and 8E–H). At the top of the limestones, a 5–10 cm layer of washed-away red shales of the Malinowa Fm., followed by the basal portion of the Jarmuta conglomerates, can be observed. The Jarmuta conglomerates are composed of pebbles and cobbles both of the PKB and of exotic material as well as clasts of the Malinowa red shale and cherty limestone (WP 943).

BIOSTRATIGRAPHY

MATERIAL AND METHODS

Biostratigraphical studies have been carried out on 71 samples collected during 2006–2011 for foraminiferal studies. Apart from these, some thin sections have also been studied. The samples were collected from the Wronine, Szlachtowa, Opaleniec, CKH and Malinowa formations in the following sections: Zabaniszcze (18 samples), Sztolnia A (8 samples), B (7 samples), C (7 samples), Krupianka (10 samples), Hulina (11 samples) and 10 samples in the dispersed points of the area studied, marked by GPS way points (WP) (Fig. 1B; Table 2). Most of these samples were devoid of foraminifera or contain only traces of microfossils. The controversy concerning the age of "black flysch" arose after the studies of Sikora and Blaicher (Sikora, 1962; 1971*a*, *b*; Blaicher, 1973) and that is why we have decided to re-examine Blaicher's archived material. The samples (78) investigated by Blaicher were collected from the same outcrops as ours and they are stored in the Archives of the PGI-NRI. The results of these re-examination studies are briefly commented on while original Blaicher's results are provided in Appendices 1–4 (supplementary file*).

Whenever possible, 400 g of collected rock was carefully washed before further processing. Samples were disaggregated by repeated boiling and freezing using sodium bicarbonate solution, and then washed over a 63 µm screen and dried. Some of the samples were devoid of foraminifera, the others contain

* Supplementary files are available on website: www.gq.pgi.gov.pl

Table 3

Distribution of foraminifera in the Wronine, Szlachtowa, Opaleniec formations and CKH

Lithostratigraphy	Wr.	Szlachtowa Fm.						Opaleniec Fm.							CKH				
Samples	Zab. 10/10	Zab. 9/10	Szt. 14/01	Szt. 18/01	WP 317	Szt. B above BW	Szt. 17/06	Szt. 16/06	Hul. 40/07	Hul. 39/07	Szt. 3/06	Szt. 9/06	Szt. 30/01	Szt. 11/06	Szt. 19/06	Szt. 8/06	Hul. 33/07	Hul. 32/07	Hul. 36/07
Microfauna	Early Cretaceous–Albian										Albian–Cenomanian								
Bathysiphon sp.												x	x	x			x		
Nothia sp.											x								
Rhabdammina sp.		x						x		x							x		
Rhizammina indivisa				x									x						
Rhizammina sp.		x			x	x	x	x	x	x	x	x		x	x		x		
Psammosphaera sp.		x		x	x	x													
Saccammina aff. *crespinae*							x												
Hyperammina gaultina		x									x			x					
Hyperammina sp.		x			x	x	x	x							x				
Jaculella depressa		x					x				x	x	x				x		
Ammodiscus cretaceus										x									
Ammodiscus siliceus												x							
Ammodiscus tenuissimus													x						
Ammodiscus sp.										x							x		
Glomospira charoides										x									
Glomospira gordialis	x			x				x	x		x	x	x	x	x	x	x	x	
Glomospira irregularis				x															
Glomospirella gaultina	x																		
Glomospirella sp.																		x	
Kalamopsis grzybowskii		x								x							x		
Pseudonodosinella troyeri								x	x										
Caudammina crassa	x									x									
Caudammina ovula			x																
Cribrostomoides nonioninoides			x					x	x	x							x		
Haplophragmoides cf. *concavus*											x								
Haplophragmoides kirki														x					
Haplophragmoides div. sp.	x	x					x	x		x	x				x		x		
Ammosphaeroidina sp.														x		x		x	
Recurvoides div. sp.													x						
Thalmannammina sp.									x	x				x					
Bulbobaculites sp.								x		x	x	x	x	x	x		x		
Ammobaculoides carpathicus		x		x	x	x													
Textulariopsis sp.					x														
Plectorecurvoides sp.								x	x	x									
Pseudobolivina sp.										x							x		
Trochammina (Ammogloborotalia) abrupta				x			x	x			x	x		x	x		x		
Trochammina aff. *quinqueloba*							x												
Trochammina cf. *vocontiana*		x																	
Trochammina sp.			x						x	x									
Verneuilinoides neocomiensis			x	x															
Verneuilinoides sp.			x					x						x	x				
Gaudryina sp.	x																		
Gaudryinella sp.																	x		
Tritaxia cf. *gaultina*										x									
Tritaxia sp.								x	x										
Praedorothia sp.												x						x	

Tab. 3 cont.

Lithostratigraphy	Wr.	Szlachtowa Fm.						Opaleniec Fm.							CKH				
Samples	Zab. 10/10	Zab. 9/10	Szt. 14/01	Szt. 18/01	WP 317	Szt. B above BW	Szt. 17/06	Szt. 16/06	Hul. 40/07	Hul. 39/07	Szt. 3/06	Szt. 9/06	Szt. 30/01	Szt. 11/06	Szt. 19/06	Szt. 8/06	Hul. 33/07	Hul. 32/07	Hul. 36/07
Microfauna	Early Cretaceous–Albian										Albian–Cenomanian								
Dorothia oxycona																		x	
Dorothia sp.							x		x								x		
Trocholina sp.							x												
Superfamily Nodosariacea	x	x	x	x			x	x	x			x	x	x	x	x	x		
Heterohelix sp.							x												
Planomalina sp.	x																		
Hedbergella indet.											x							x	
Whiteinella sp.																		x	
Praeglobotruncana sp.											x								
Rotaliporids indet.							x											x	
Globotruncana sp.															x				
Marginotruncana sp.											x				x				
Gyroidinoides infracretaceus									x										
Gyroidinoides div. sp.	x																	x	
Gavelinella sp.																		x	
Radiolaria moulds	x					x	x	x		x	x					x	x	x	x
Sponge spicules		x			x		x										x		
Echinodermata spicules													x						
Crinoid elements													x						
Ostracoda		x											x		x				

Wr. – Wronine Formation

varied amounts. Foraminiferal examination was performed on the specimens picked from the >125 µm fraction as the smaller fraction was almost devoid of identifiable taxa. The number of specimens, species diversity and states of preservation varied from sample to sample. Processing of samples was performed both in the micropalaeontological labaratories of the Institute of Geological Sciences of the Jagiellonian University and the Carpathian Branch of the PGI-NRI. Some of the samples were divided into two parts and simultaneously processed in both laboratories. Characteristic species of foraminifera were photographed using the SEM in the Institute of Geological Sciences at the Jagiellonian University.

Updated age designations of foraminifera identified by J. Blaicher were based on: Geroch and Nowak (1984), Riegraf and Luterbacher (1989*a*, *b*), Nagy *et al*. (1990), Kaminski *et al.* (1992), Neagu and Neagu (1995), Holbourn and Kaminski (1997), Nagy and Basov (1998), Oszczypko *et al.* (2004) and Kaminski *et al.* (2008).

RESULTS

ZABANISZCZE (FIGS. 1B AND 4C, D)

Manganiferous radiolarites (Sokolica Radiolarite Fm.)

The lowest samples were collected from the greenish shales below cherty limestones. Water-processed samples (WP 485; Fig. 4C, D) yielded rich radiolarian assemblages with an admixture of agglutinated foraminifera. Scarce representatives of *Verneuilinoides* cf. *graciosus*, *Hyperammina* sp. and *Trochammina* sp. were found.

Cherty limestones (Pieniny Limestone Fm.)

A thin section from the limestone (WP 487) allowed for precise stratigraphic designation due to numerous representatives of the calcareous dinocyst *Parastomiosphaera malmica* Borza indicating the upper part of the Early Tithonian *Parastomiosphaera malmica* Zone (Rehakova, 2000). This result confirms earlier age determination (Nowak, 1971; Obermajer, 1986).

Wronine Fm.

The dark calcareous shales yielded poor assemblages of agglutinated and calcareous foraminifera (Table 3), among others: *Hyperammina* cf. *gaultina*, *Trochammina* cf. *neocomiana*, and *Dentalina* aff. *nana* known from the Early Cretaceous. The results agree with earlier data of Blaicher (1973).

Sample 10/10 yielded a mixed assemblage of agglutinated and calcareous foraminifera, poorly preserved (Fig. 4C, D). The following taxa have been recognized: *Glomospira gordialis, Glomospirella gaultina, Caudammina crassa* (Fig. 11A), *Gaudryina* sp., *Gyroidinoides* sp. and individual specimens of *Lenticulina* accompanied by pyritized moulds of radiolarians.

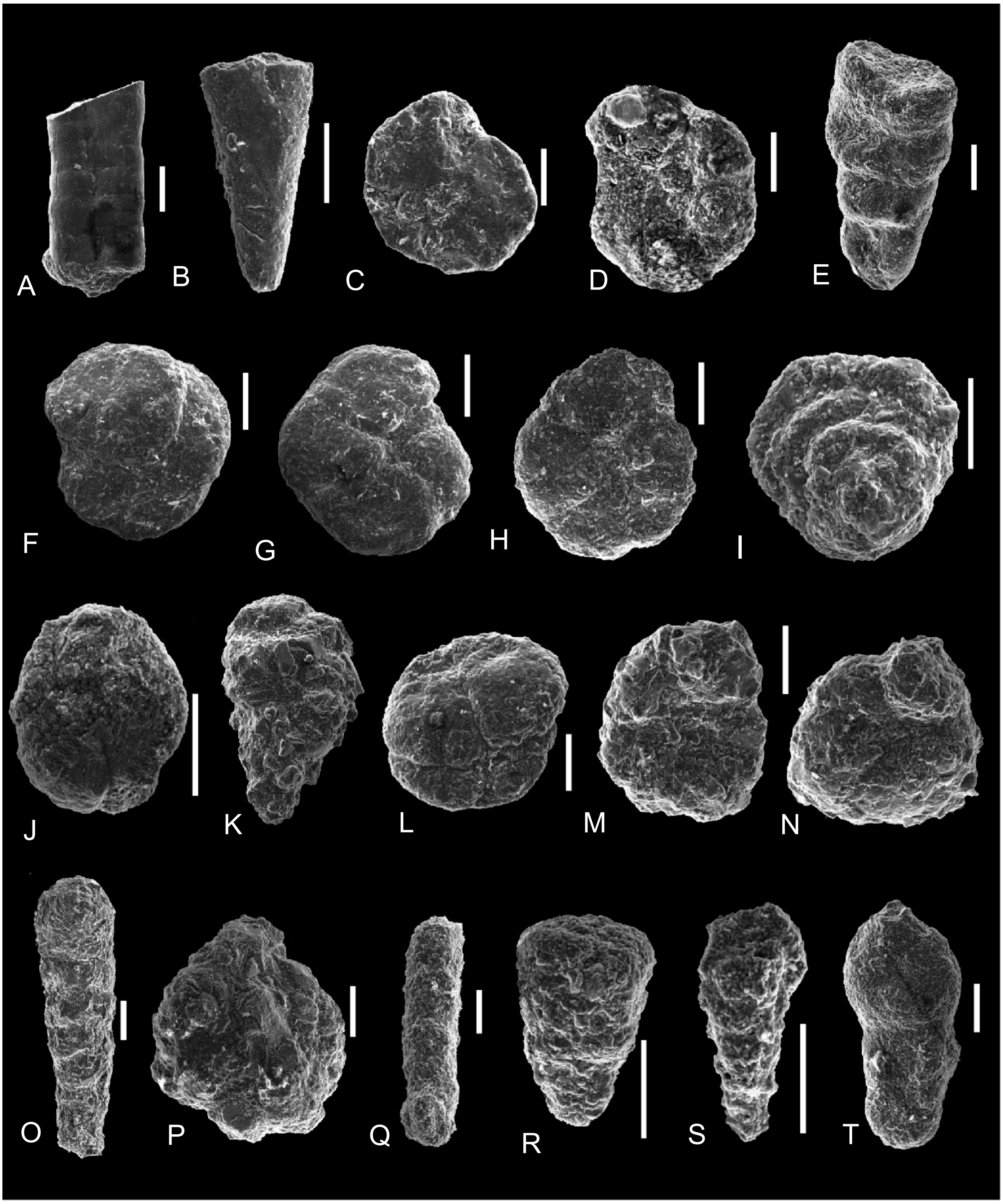

Fig. 10. Microphotographs of agglutinated foraminifera of the Szlachtowa (Sztolnia) and Opaleniec formations (specimens selected by B. Olszewska from recent samples (WP) from the Zabaniszcze and Krupianka section and archived assemblages of J. Blaicher (16/68))

A – *Hyperammina* sp., side view, Szlachtowa Fm., WP 490; **B** – *Jaculella depressa* Vašiček, side view, Szlachtowa Fm., Zab. WP 490a; **C** – *Haplophragmoides canuiformis* Dain, side view, Szlachtowa Fm., Zab. WP 490; **D** – *Ammobaculites* cf. *praegoodlandensis* Bułynnikova, initial part, Szlachtowa Fm., Zab. WP 490a; **E** – *Eomarssonella paraconica* Levina, side view, Szlachtowa Fm., WP 490; **F** – *Trochammina parviloculata* Gerke and Scharovskaya, umbilical side, Szlachtowa Fm., Zab. WP 489; **G** – *Trochammina* cf. *canningensis* Tappan, umbilical side, Szlachtowa Fm., Zab. WP 489; **H** – *Trochammina* cf. *canningensis* Tappan, spiral side, Szlachtowa Fm., Zab. WP 489; **I** – *Trochammina* cf. *topagorukensis* Tappan, spiral side, Szlachtowa Fm., Zab. WP 489; **J** – *Trochammina* cf. *septentrionalis* Scharovskaya, spiral side, Szlachtowa Fm., Zab. 12/68; **K** – *Verneuilinoides graciosus* Kosyreva, side view, Szlachtowa Fm., Zab. 16/68; **L** – *Trochammina parviloculata* Gerke and Scharovskaya, umbilical side, Szlachtowa Fm., Zab. 23/39; **M** – *Trochammina* (=*Ammogloborotalia*) *abrupta* Geroch, spiral side, Szlachtowa Fm., Sztolnia A, 8/69; **N** – *Trochammina* (=*Ammogloborotalia*) *abrupta* Geroch, umbilical side, Szlachtowa Fm., Sztolnia A, 8/69; **O** – *Ammobaculoides carpathicus* Geroch, uniserial part, Szlachtowa Fm., Sztolnia A, 8/69; **P** – *Thalmannammina anastasiui* Neagu, side view, Szlachtowa Fm., Sztolnia A, 7/69; **Q** – *Bulbobaculites elongatulus* Dain, edge view, Szlachtowa Fm., Sztolnia A, 8/69; **R** – *Verneuilinella carpathica* Neagu and Neagu, side view, Szlachtowa Fm., Krup. 139 802; **S** – *Verneuilinoides graciosus* Kosyreva, side view, Szlachtowa Fm., Krup. WP 215b; **T** – *Pseudonodosinella troyeri* Tappan, side view, Opaleniec Fm., Sztolnia B, 8/71; scale bar = 100 μm

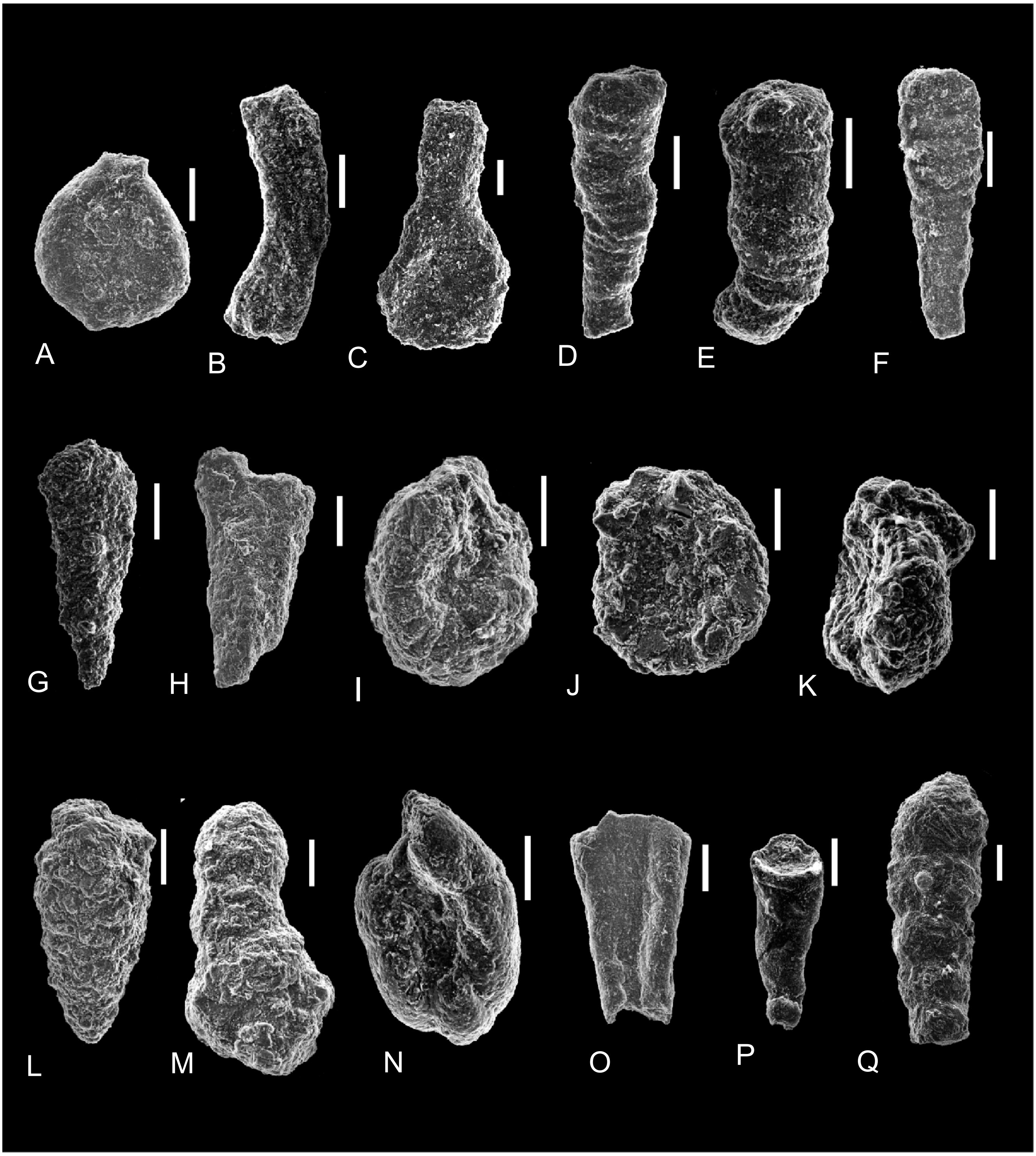

Fig. 11. Microphotographs of characteristic agglutinated foraminifera from the Wronine, Szlachtowa and Opaleniec formations (specimens selected by E. Malata)

A – *Caudammina crassa* (Geroch), Wronine Fm., Zab. 10/10; **B** – *Rhizammina* sp., Szlachtowa Fm., Zab. 9/10; **C** – *Hyperammina gaultina* Ten Dam, Szlachtowa Fm., Zab. 9/10; **D** – *Ammobaculoides carpathicus* Geroch, Szlachtowa Fm., Zab. 9/10; **E** – *Ammobaculoides carpathicus* Geroch, Szlachtowa Fm., Zab. 9/10; **F** – *Ammobaculoides carpathicus* Geroch, Szlachtowa Fm., Zab. 9/10; **G** – ?*Textulariopsis* sp. Szlachtowa Fm., WP 317; **H** – *Jaculella depressa* (Vašiček), Opaleniec Fm., Szt. 9/06; **I** – *Trochammina* (=*Ammogloborotalia*) *abrupta* Geroch (umbilical side), Opaleniec Fm., Szt. 9/06; **J** – *Trochammina* (=*Ammogloborotalia*) *abrupta* Geroch (spiral side), Opaleniec Fm., Szt. 9/06; **K** – *Trochammina* (=*Ammogloborotalia*) *abrupta* Geroch, Opaleniec Fm., Szt. 9/06; **L** – *Verneuilinoides* sp., Opaleniec Fm., Szt. 9/06; **M** – *Bulbobaculites* sp., Opaleniec Fm., Szt. 9/06; **N** – *Cribrostomoides nonioninoides* (Reuss), CKH, Hul. 33/07; **O** – *Jaculella depressa* (Vašiček), CKH, Hul. 33/07; **P** – *Jaculella depressa* (Vašiček), CKH, Hul. 33/07; **Q** – *Bulbobaculites* sp., CKH, Hul. 33/07; scale bar = 100 μm

Table 4

Distribution of foraminifera in the Malinowa Shale Fm. (according to E. Malata)

Lithostratigraphy	Malinowa Formation									
Samples	Szt. 1/05/07	Szt. 7/06	WP 222	WP 141	Szt. 14/06	Zab. 2/10	Hul. 41/07	Hul. 31/07	Szt. 23/07	Szl. WP 24
Microfauna	Turonian						Con–S			C
Bathysiphon sp.										x
Nothia excelsa		x	x	x	x	x	x			x
Nothia robusta										x
Rhabdammina sp.							x			x
Rhizammina sp.		x			x	x				x
Placentammina placenta							x			x
Ammodiscus cretaceus					x	x	x			x
Ammodiscus peruvianus										x
Ammodiscus siliceus		x								
Glomospira charoides					x	x	x			
Glomospira gordialis		x	x	x			x	x	x	x
Glomospira irregularis		x	x			x				
Subreophax sp.		x								
Pseudonodosinella troyeri					x					
Caudammina gigantea							x			x
Caudammina ovula	x						x			
Cribrostomoides sp.										x
Haplophragmoideds bulloides		x								
Haplophragmoides kirki					x				x	
Haplophragmoides sp.		x	x		x	x	x			
Labrospira pacifica							x			
Praesphaerammina sp.						x				
Paratrochamminoides div. sp.		x				x	x	x	x	
Trochamminoides grzybowskii										x
Ammosphaeroidina pseudopauciloculata			x					x		
Recurvoides div. sp.		x			x	x	x	x	x	x
Thalmannammina subturbinata						x	x			
Thalmannammina sp.				x					x	
Bulbobaculites problematicus			x	x						
Spiroplectammina praelonga			x							
Spiroplectam. subhaeringensis	x							x		
Spiroplectinella costata						x	x			
Plectorecurvoides sp.			x				x		x	
Trochammina cf. *umiatensis*							x			
Trochammina globigeriniformis		x			x					x
Trochammina globolaevigata	x									
Trochammina sp.					x					
Karrerulina conversa										x
Gerochammina lenis				x		x	x			
Gerochammina obesa					x		x			
Gerochammina stanislawi		x		x						
Uvigerinammina jankoi			x	x	x	x	x			
Tritaxia amorpha	x									
Tritaxia gaultina	x		x					x	x	
Tritaxia subparisiensis					x		x		x	
Tritaxia sp.	x			x	x	x	x		x	
Arenobulimina sp.							x			
Remesella sp.	x							x		
Dorothia crassa			x				x			
Dorothia oxycona								x		
Lenticulina sp.	x									
Astacolus sp.		x								
Whiteinella sp.	x									
Praeglobotrunca sp.	x									
Rotalipora sp.		x								
Contusotruncana fornicata					x					
Globotruncana linneiana							x			
Globotruncanita stuartiformis							x			
Globotruncanita sp.							x			
Pleurostomella cf. *subnodosa*	x									
Pleurostomella sp.	x									
Allomorphina sp.	x									
Charltonina sp.	x									
Gyroidinoides div. sp.	x							x		
Radiolaria moulds								x		

Con–S – Coniacian–Santonian, C – Campanian

Szlachtowa Fm.

Samples WP 489, 490 (Fig. 4C, D) contained, specifically similar, assemblages of agglutinated foraminifera, pyrite moulds of radiolarians, and sponge spicules. The foraminiferal assemblage included: *Hyperammina* sp. (Fig. 10A), *Jaculella depressa* (Fig. 10B), *Ammobaculites* cf. *praegoodlandensis* (Fig. 10D), *Eomarssonella paraconica* (Fig. 10E, WP 490), *Ammobaculoides carpathicus*, *Haplophragmoides canuiformis* (Fig. 10C), *Trochammina* cf. *topagorukensis* (Fig. 10I), *T. parviloculata* (Fig. 10F), *T.* cf. *canningensis* (Fig.10G, H), *Verneuilinella carpathica* and *Verneuilinoides* cf. *graciosus*. The specific composition of the assemblages is similar to those from the archived material from the same section (see Appendix 1).

The agglutinated taxa *Rhizammina* sp. (Fig. 11B), *Hyperammina gaultina* (Fig. 11C), *Hyperammina* sp. *Rhabdammina* sp., *Kalamopsis grzybowskii* dominate the assemblage from sample 9/10 (Fig. 4C, D and Table 3). The species *Jaculella depressa* and *Ammobaculoides carpathicus*

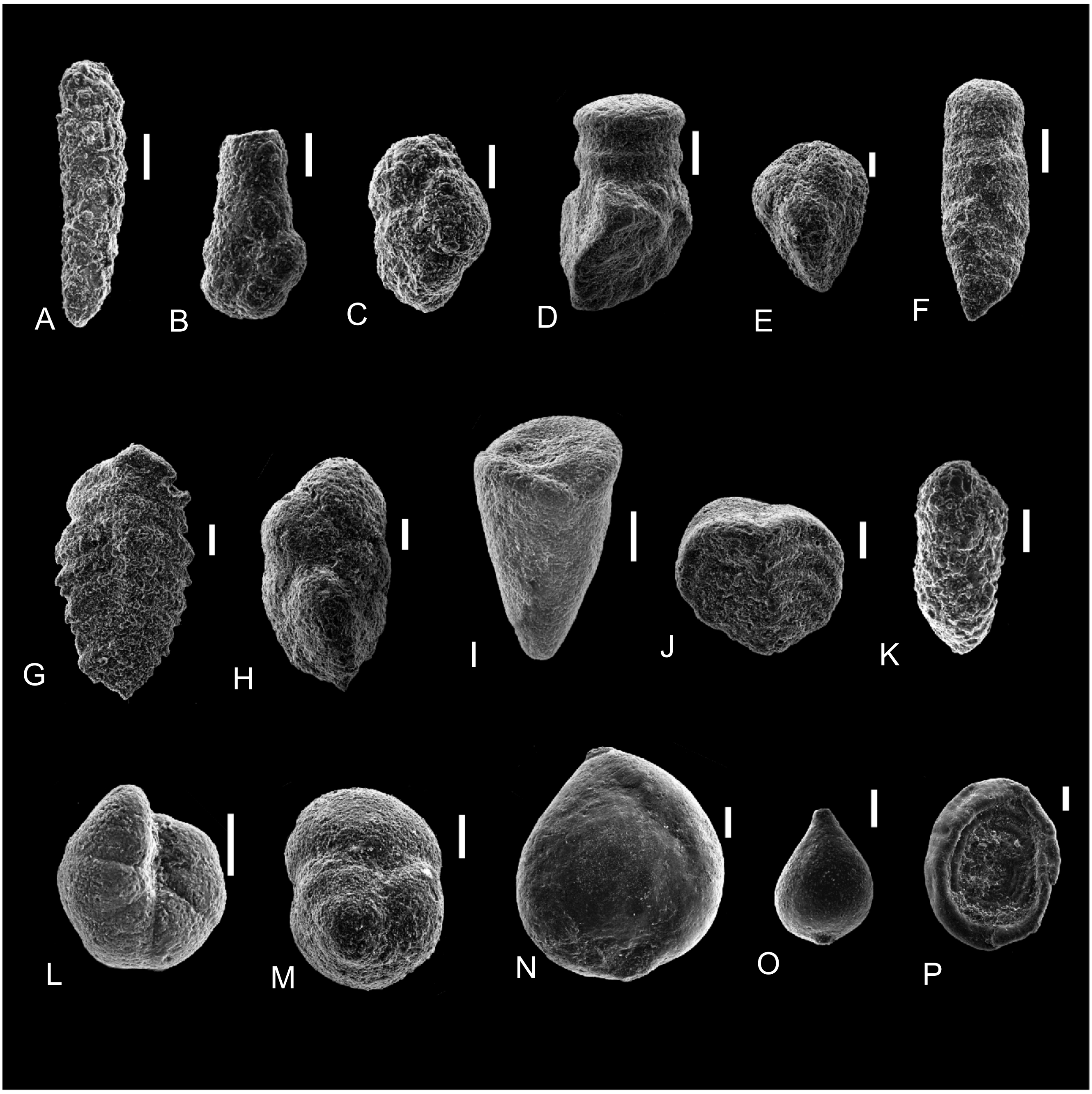

Fig. 12. Microphotographs of characteristic agglutinated foraminifera of the Malinowa Shale Fm. (specimens selected by E. Malata)

A – *Gerochammina stanislawi* Neagu, Szt. 7/06; **B** – *Bulbobaculites problematicus* (Neagu), WP 141; **C** – *Uvigerinammina jankoi* Majzon, WP 222; **D** – *Tritaxia gaultina* (Morozova), Hul. 31/07; **E** – *Tritaxia* sp., Hul. 41/07; **F** – *Tritaxia amorpha* (Cushman), Szt. 1/05/07; **G** – *Spiroplectinella costata* (Huss), Hul. 41/07; **H** – *Tritaxia subparisiensis* (Grzybowski), Hul. 41/07; **I** – *Dorothia oxycona* (Reuss), Hul. 31/07; **J** – *Spiroplectammina subhaeringensis* (Grzybowski), Hul. 31/07; **K** – *Gerochammina lenis* (Grzybowski), WP 222; **L** – *Haplophragmoide bulloides* (Beissel), Szt. 7/06; **M** – *Trochammina globolaevigata* Beckmann, Szt. 1/05/07; **N** – *Caudammina gigantea* (Geroch), WP 24; **O** – *Caudammina ovula* (Grzybowski), WP 24; **P** – *Ammodiscus cretaceus* (Reuss), WP 24; scale bar = 100 µm

(Fig. 11D–F) are stratigraphically important elements of this assemblage. There are also some specimens identified as *Trochammina* cf. *vocontiana*, though their state of preservation is so bad that this identification is uncertain. Apart from agglutinated foraminifera there are also calcareous species representing the Nodosariacea as well as pyritised moulds of radiolaria, sponge spicules and some ostracods.

Malinowa Shale Fm.

Sample 2/10 (Fig. 4A) yielded an agglutinated assemblage with the characteristic species *Uvigerinammina jankoi* (Table 4).

SZTOLNIA SECTION A

Szlachtowa Fm.

The samples from this formation generally contain very poor assemblages. In sample 17/06 (Fig. 5) the tubular morphotypes *Rhizammina* sp. and *Hyperammina* sp. are dominant accompanied by rare specimens of *Jaculella depressa, Trochammina* (= *Ammogloborotalia*) *abrupta* and *Dorothia subtrochus* (Table 3). A few specimens of *Lenticulina* and an admixture of Upper Cretaceous planktonic forms (e.g., rotaliporids indet., *Heterohelix* sp.) as well as sponge spicules and pyrite radiolarian moulds are also present.

Opaleniec Fm.

In sample 3/06 (Fig. 5) agglutinated foraminifera are represented by long-ranging *Nothia* sp., *Rhizammina* sp., *Hyperammina gaultina,* and *Glomospira gordialis. Jaculella depressa* and *Trochammina* (=*Ammogloborotalia) abrupta* are stratigraphically more important species in this assemblage. The form designated as *Bulbobaculites* sp. has been noticed in most assemblages from this formation. The specimens of this taxon are usually broken, so species determination is generally impossible. Radiolarian moulds and a few specimens of Late Cretaceous planktonic foraminifera, varying in colour, have been also noticed (Table 3).

Sample 16/06 (Fig. 5) yielded a less numerous assemblage with individual specimens of *Pseudonodosinella troyeri, Cribrostomoides* cf. *nonioninoides* and *Plectorecurvoides* sp. apart from the characteristic component *Trochammina* (=*Ammogloborotalia*) *abrupta* and *Bulbobaculites* sp. Radiolarian moulds and a few specimens of *Lenticulina* have been also found (Table 3).

SZTOLNIA SECTION B

Opaleniec Fm.

In sample 9/06 *Jaculella depressa*, *Trochammina* (=*Ammogloborotalia*) *abrupta* and *Bulbobaculites* sp. are characteristic agglutinated components of the foraminiferal assemblage (Fig. 11H, I–K, M) while the calcareous foraminifera are represented by nodosarids. Apart from foraminifera there are elements of crinoids, echinoids and some ostracods. Two specimens of Paleogene planktonic foraminifera have been also noticed (Table 3).

The assemblage from sample 11/06 is similar in the overall character to the one described above. Besides *Trochammina* (=*Ammogloborotalia*) *abrupta* and *Bulbobaculites* sp. there are *Haplophragmoides kirki, Ammosphaeroidina* sp., *Thalmannammina* sp. and *Verneuilinoides* sp. The calcareous representatives of nodosarids are relatively numerous with *Lenticulina ouachensis* among them. Some ostracods and abundant calcified radiolarian moulds are also present (Table 3).

Cenomanian Key Horizon

Sample 8/06 (Fig. 5) consists of numerous radiolarian moulds and individual specimens of non-characteristic agglutinated foraminifera such as *Glomospira gordialis* and *Ammosphaeroidina* sp. and some nodosarids. In most samples from this unit there are only radiolarian moulds in various states of preservation (Table 3).

Malinowa Shale Fm.

A mixed assemblage has been recovered from sample 1/05/07 (Table 4). The agglutinated component consists of *Caudammina ovula, Trochammina globolaevigata* (Fig. 12M) and of a few taxa whose characteristic feature is the calcareous cement. These are *Spiroplectammina subhaeringensis, Tritaxia amorpha* (Fig. 12F), *T. gaultina* and *Remesella* sp. Apart from these agglutinated forms there are also some calcareous foraminifera, both, benthic and planktonic. Planktonic ones are represented by individual specimens of poorly preserved *Praeglobotruncana* and rotaliporids. The stratigraphic ranges of the above-mentioned species suggest a Turonian or Turonian/Coniacian age (Gawor-Biedowa *et al*., 1984; Bolli *et al*., 1994).

Sample 7/06 yielded a relatively poor assemblage with agglutinated taxa such as *Ammodiscus siliceus, Glomospira gordialis, G. irregularis, Paratrochamminoides* div. sp, *Haplophragmoides bulloides* (Fig. 12L) *Recurvoides* div. sp., *Trochammina globigeriniformis* and *Gerochammina stanislawi* (Fig. 12A). There are also individual specimens of *Astacolus* and rotaliporids (Table 4).

The foraminiferal assemblage recovered from sample 14/06 (Fig. 5) is dominated by agglutinated taxa with the characteristic species *Uvigerinammina jankoi* and *Tritaxia subparisiensis.* A single specimen of *Contusotruncana fornicata* was also found. The overlapping ranges of these taxa indicate a Coniacian–Santonian age for the assemblage (Gawor-Biedowa *et al*., 1984).

SZTOLNIA SECTION C

Cenomanian Key Horizon

Sample 19/06 (Fig. 5) yielded an assemblage dominated by calcareous nodosarids, mainly *Lenticulina*, with some agglutinated taxa such as *Trochammina* (=*Ammogloborotalia*) *abrupta* and *Bulbobaculites* sp. A few specimens of badly preserved Late Cretaceous planktonic foraminifera have also been recovered (Table 3).

KRUPIANKA STREAM SECTION

Szlachtowa Fm.

Three thin sections (Fig. 2; WP 215a, b, 216) of the subdivision were examined for microfossils. Micaceous mudstones (WP 215a, b) contained a poor assemblage of foraminifera: *Verneuilinoides graciosus* (Fig. 10S), *Trochammina* cf. *neocomiana*, *Spirillina* sp., *Trocholina* sp. of Kimmeridgian–Tithonian character.

The presence of these forms in sandstones additionally excludes a Middle Jurassic age for the Szlachtowa Fm., as postulated by Birkenmajer and Pazdro (1968) and Birkenmajer (1977).

Cenomanian Key Horizon

A thin section (Fig. 2; WP 218) was made from the cherty limestone. The microfossil assemblage was characterized by the presence of the rare calcareous dinocysts *Colomisphaera* cf. *cieszynica* Nowak, *C. vogleri* (Borza) and nannoconids. The nannoconids permit correlation of the assemblage with those described by Nowak (1971) and Obermajer (1986) from similar lithologies of Valanginian–Hauterivian age. Comparison with the other sections suggests a Cenomanian age as a possible interpretation and the redeposition of the older microfossils (dinocysts).

HULINA SECTION (FIGS. 1B AND 9)

Opaleniec Fm.

The agglutinated component of the assemblages consists of *Rhizammina* sp., *Ammodiscus cretaceus, Glomospira gordialis* and *Cribrostomoides nonioninoides.* In sample 39/07

Caudammina crassa and *Haplophragmoides falcatosuturalis* have been found as well as some radiolarian moulds (Table 3). Sample 40/07 contains also *Pseudonodosinella troyeri* and calcareous *Gyroidinoides infracretaceus* as well as some specimens of *Lenticulina.*

Cenomanian Key Horizon

There are only radiolarian moulds present in most samples from this formation. Sample 33/07 yielded a microfossil assemblage similar in character and composition to that of the Opaleniec Fm. with the agglutinated taxa *Jaculella depressa* (Fig. 11O, P) *Trochammina* (=*Ammogloborotalia*) *abrupta, Bulbobaculites* sp. (Fig. 11Q) and a single specimen of *Cribrostomoides nonioninoides* (Fig. 11N). There are also some nodosarids, radiolarian moulds and sponge spicules (Table 3).

Sample 32/07 contains a less abundant assemblage, different in species composition, with agglutinated foraminifera such as *Glomospirella* sp., *Glomospira gordialis, Trochammina* cf. *wetteri* and *Dorothia oxycona.* Calcareous benthic foraminifera are represented by *Gyroidinoides* div. sp., *Gavellinella* sp. There are also a individual specimens of planktonic genera such as *Hedbergella* sp., *Whiteinella* sp. and rotaliporids. Radiolarian moulds are numerous (Table 3).

Malinowa Shale Fm.

Sample 31/07 contains an assemblage with agglutinated species which display calcareous cement such as *Spiroplectammina subhaeringensis* (Fig. 12J), *Tritaxia gaultina* (Fig. 12D) and *Dorothia oxycona* (Fig. 12I). The stratigraphic ranges of these taxa indicate a Coniacian–Santonian age for this assemblage (Gawor-Biedowa *et al.*, 1984).

Sample 41/07 yielded a diverse assemblage with agglutinated index taxa of two or even three zones distinguished in the Polish Outer Carpathians (Olszewska, 1997) representing the Turonian–Campanian time span. There are *Uvigerinammina jankoi, Spiroplectinella costata* (Fig. 12G) and *Caudammina gigantea.* A few specimens of planktonic foraminifera such as *Globotruncana linneiana* and *Globotruncanita stuartiformis* have been also found (Table 4).

GRAJCAREK STREAM AT SZLACHTOWA AND OTHER ADJACENT SITES

Szlachtowa Fm.

Tubular morphotypes of the agglutinated foraminifera *Rhizammina* sp. and *Hyperammina* sp. are the main components of the poor assemblage from sample WP 317 (Figs. 1B and 2; Table 2). However, a few specimens of *Ammobaculoides carpathicus* and very poorly preserved form of ?*Textulariopsis* sp. (Fig. 11G) are worth mentioning. Apart from foraminifera sponge spicules are also present (Table 3).

Samples WP 357/2–3 (Fig. 1B and Table 2) from dark grey shales with red intercalations (Szlachtowa lithofacies), sampled on the right bank of the Grajcarek Stream in Szlachtowa, revealed the presence of *Thalmannammina subturbinata*, *Ammosphaeroidina pseudopauciloculata* and *Parathalmanninella appenninica* indicating a Late Albian–Early Cenomanian age for the assemblage

At the mouth of the Sielski Stream, red shales (sample WP 370) yielded a typical poor foraminiferal assemblage composed of *Bathysiphon* sp., *Nothia excelsa*, *Hedbergella planispira* and rare radiolarians. The age of the assemblage is Late Cretaceous (probably not younger than Turonian). The spotted limestones (sample WP 943) yielded a rich nannoconid assemblage with *Nannoconus* aff. *minutus* Brönnimann (Hauterivian–Cenomanian).

Malinowa Shale Fm.

Samples: Szlachtowa, Sielski Stream, Jaworki, WP 222/444 and Kamionka Stream, WP 141 (Fig. 1B and Table 2) contained only agglutinated foraminifera with the characteristic species *Bulbobaculites problematicus* (Fig. 12B), and *Uvigerinammina jankoi* (Fig. 12C) whose overlapping ranges fall within the Turonian–Coniacian (Geroch and Nowak, 1984).

The assemblage from sample WP 24 represents a typical agglutinated assemblage with *Caudammina gigantean* (Fig. 12N).

RE-EXAMINATION OF THE J. BLAICHER ARCHIVED COLLECTION

Previous micropalaeontological investigations were carried out by the late Olga Pazdro (Polish Academy of Sciences Warszawa) and Jadwiga Blaicher (PGI Kraków). These authors, while studying samples from the same sections, gave different age determinations. Pazdro (1979) based her age diagnoses (Middle Jurassic) on the calcareous foraminifera whereas Blaicher (1973) suggested an Early Cretaceous age based on assemblages of agglutinated forms. However, it should be emphasized, that the former author reported also Cretaceous representatives of the family Nodosariidae (Pazdro, 1979). Age controversy still persists regardless of the new biostratigraphic data from studies of foraminifers, calcareous nannoplankton (Oszczypko *et al*., 2004) and organic dinocysts (Birkenmajer *et al*., 2008; Gedl, 2008*a*, *b*).

The original material (washed residues of samples and foraminiferal assemblages) studied by J. Blaicher in four archived sections were the subject of the micropalaeontological re-examinations, performed by B. Olszewska: Zabaniszcze, Sztolnia A, B and Krupianka streams. The original Blaicher's data are provided in Appendices 1–4. Only new taxa identified in re-examined assemblages are reported below.

According to J. Blaicher, the Szlachtowa and Opaleniec .formations are of Early Cretaceous age while the radiolarian shales, and radiolarites (CKH) and variegated shales of the Malinowa Fm. belongs to the Late Cretaceous.

Wronine Fm.

Re-examination of the archive faunal slides from the Wronine Fm. (Zabaniszcze C) confirmed the taxonomical identifications of Blaicher. In the lower part of the formation the presence of *Marssonella hauteriviana* and *Globigerinelloides* cf. *blowi* have been confirmed. In the upper part of the section *Gyroidina infracretacea*, *Hedbergella* cf. *trocoidea*, *Discorbis wassoewizi* and *Plectorecurvoides alternans* were also found (Appendix 1).

Szlachtowa Fm.

The re-examined archive material of the Szlachtowa Fm. (Zabaniszcze C; samples 12/68–24/68) contained poor assemblages composed of agglutinated species: *Verneuilinella carpathica*, *Trochammina* cf. *septentrionalis* (Fig. 10J), *T.* cf. *topagorukensis*, *T.* cf. *squamatiformis*, *Gaudryina* cf. *gerkei*, *Verneuilinoides* cf. *graciosus* (Fig. 10K), *Ammobaculites*

Table 5

Stratigraphic occurrence of the foraminiferal taxa recovered from the Szlachtowa Fm. (based on the literature mentioned in the *Biostratigraphy* section in this paper)

Foraminifera from the Szlachtowa Fm.	Oxfordian	Kimmeridgian	Tithonian	Berriasian	Valanginian	Hauterivian	Barremian	Aptian	Albian	Cenomanian
Rotaliporids									X	X
Plectorecurvoides alternans									X	X
Marssonella subtrochus							X	X	X	
Caudammina crassa							X	X	X	X
Lenticulina praegaultina							X			
Jaculella depressa						X	X	X	X	X
Falsogaudryinella tealbyensis					X	X	X			
Hyperammina gaultina				X	X	X	X	X	X	
Cribrostomoides nonioninoides				X	X	X	X	X	X	
Trochammina vocontiana				X	X	X	X	X	X	
Gaudryina gerkei				X	X					
Trochammina (Ammoglob.) abrupta			X	X	X	X	X	X	X	X
Ammobaculoides carpathicus			X	X	X	X	X	X		
Trochammina parviloculata			X	X						
Bulbobaculites elongatulus			X							
Ammobaculites praegoodlandensis			X							
Trochammina septentrionalis			X							
Verneuilinoides postgraciosus		X	X							
Trochammina rosacea		X	X							
Verneuilinoides graciosus		X	X							
Haplophragmoides canuiformis		X	X							
Thalmanammina anastasiui		X								
Verneuilinella carpathica		X								
Eomarsonella paraconica	X	X	X							
Pseudomarssonella dumortieri	X	X	X							
Spirillina elongata	X	X	X							
Trochammina topagorukensis	X	X	X							
Trochammina minutissima	X	X								
Rumanolina seiboldi	X									
Paalzowella turbinella	X									

praegoodlandensis. The foraminifera are accompanied by pyrite moulds of radiolarians. Sample 15/68 contained an admixture of planktonic representatives of *Dicarinella* and rotaliporids.

The stratigraphic distribution of agglutinated taxa mentioned above (Table 5) shows that the older assemblage of foraminifera is of Kimmeridgian–Tithonian age while the youngest belongs to the Albian.

The content of archive cells from the Sztolnia A section is very poor and contains mixed ?Jurassic/Early Cretaceous–Late Cretaceous foraminifera. Characteristic is the persistent presence of radiolarians (Appendix 2).

Re-examination (Appendix 4) of archive cells from the Krupianka section partly confirmed the results of earlier investigations. The washed residuum of the archive sample 5/69 yielded rich a assemblage of the agglutinated species: *Hyperammina* sp., *Glomospira gordialis*, *Bulbobaculites elongatulum*, *Trochammina* cf. *rosacea*, *Verneuilinoides postgraciosus*, *Verneuilinella carpathica*, *Pseudomarssonella dumortieri*, *Recurvoides* sp., *Rumanolina feifeli*, *Spirillina* cf. *elongata*, and *Lenticulina* div.sp. Characteristic is also the presence of numerous pyrite moulds of radiolarians.

Opaleniec Fm.

Re-examined archive cells from the Sztolnia A section contained mixed assemblages composed of Jurassic, Early–Late Cretaceous and Paleogene foraminifera. In a few cases (samples 9/69, 8/69, 7/69) it was possible to examine the washed residuum.

Sample 9/69, apart from the calcareous long-lived *Lenticulina muensteri*, *L. prima*, *Vaginulinopsis matutinus*, contained numerous agglutinated taxa, such as *Rhizammina* sp., *Glomospira gordialis*, *Ammobaculites* sp., *Trochammina* cf. *annae*, *T.* cf. *canningensis*, *Thalmannammina anastasiui* and numerous radiolarians. Sample 8/69 contained exclusively agglutinated foraminifera, including: *Ammobaculoides carpathicus* (Fig. 10O), *Pseudoreophax cisovnicensis*, *Bulbobaculites* cf. *elongatulus* (Fig. 10Q), *Trochammina* (*Ammogloborotalia*) *abrupta* (Fig. 10M, N), *Verneuilinoides* cf. *neocomiensis*, *V.* cf. *kirillae*, *Thalmannammina anastasiui*, *Spirillina elongata*. The foraminifera are accompanied by numerous radiolarians.

Re-examination of the residues of archived samples, from the lower part of the subdivision, suggests that the oldest foraminiferal assemblages may not be older than the Late Kimmeridgian–Tithonian.

Examination of the washed residue of sample 7/69 revealed abundant radiolarians and rare (predominantly agglutinated) foraminifera. This assemblage was composed of: *Glomospira gordialis*, *Ammodiscus* sp., *Ammobaculoides carpathicus*, *Bulbobaculites* cf. *elongatum*, *Spiroplectammina ammovitrea*, *Thalmannammina anastasiui* (Fig. 10P), *Verneuilinella carpathica*, *Astacolus decalvatus*, *Lenticulina* ex gr. *quenstedti*.

The archive assemblages from the lower part of the formation in Sztolnia B (Large Waterfall) contained *Trochammina* (=*Ammogloborotalia*) *abrupta*, *Thalmannammina neocomiensis*, *Verneuilinoides neocomiensis* and sometimes numerous *Praedorothia ouachensis* (sample 24a).

Re-examination of the washed residues from the archive samples 8/69 and 9/69 (Krupianka section) confirmed the scarcity of foraminifera and the abundance of radiolarians (Appendix 4). No other stratigraphically significant species were recognized.

Malinowa Shale Fm.

Re-examination of the archive cells from the Sztolnia A section revealed additionally the presence of *Haplophragmoides herbichi* (sample 1/68) and *Spiroplectinella costata* (sample 16/71).

Stratigraphically significant foraminifera identified by Blaicher (1973) in the variegated beds from the Sztolnia B section include *Tritaxia gaultina*, *Uvigerinammina jankoi* and *Globotruncana* cf. *lapparenti tricarinata.* They suggest for the part of the subdivision studied a Turonian–Campanian age (Gawor-Biedowa *et al*., 1984; Geroch and Nowak, 1984; Kaminski *et al.*, 1995)

GEOLOGICAL AGE OF THE FORMATIONS STUDIED

Based on all available data the following age succession of the Grajcarek thrust-sheets in the Małe Pieniny Mts. can be proposed:

1. Manganiferous radiolarites (Sokolica Radiolarite Fm.; see Birkenmajer, 1977). A poor foraminiferal assemblage including *Verneuilinoides* cf. *graciosus* Kosyreva suggests a Kimmeridgian–Early Tithonian age.

2. Variegated radiolarites (Czajakowa Radiolarite Fm; Birkenmajer, 1977 and later papers). The sections examined thin revealed exclusively abundant radiolarians. However, Nowak (1971) recognized, in the upper part of the subdivision, the calcareous dinocyst *Parastomiosphaera malmica* (Borza), a zonal marker of the upper part of the lower Tithonian.

3. Red Aptychus marly shales of the Palenica Mb. of the Czorsztyn Limestone Fm. (see Birkenmajer, 1977), have not been sampled by us.

4. Cherty limestones (Pieniny Limestone Fm.; Birkenmajer, 1977). Late Barremian organic dinocysts have been determined at the top of formation in the Zabaniszcze section B (see Gedl, 2007).

5. Black shales, spotted limestones and black and greenish spotted shales (Kapuśnica and Wronine formations; Birkenmajer, 1977 and later papers). In the revised material of J. Blaicher the following species known only from the Cretaceous have been found: *Gyroidina infracretacea* (Morozova) (= *Valvulineria loetterlei* Tappan), *Gavelinella barremiana* Bettenstaedt, *Hedbergella trocoidea* (Gandolfi) and *Gaudryina richteri* Grabert. The Early Cretaceous age of the formations (Barremian–Albian) was supported. According to the dinocyst determinations (Zabaniszcze section B), these formations are of Late Barremian–Early Aptian age (see Gedl, 2007).

6. Szlachtowa Formation. In the lower part of the section, *Hyperammina* cf. *gaultina*, *Trochammina vocontiana*, *Marssonella subtrochus* and *Cribrostomoides* aff. *nonioninoides* were found, whose total stratigraphic range is Berriasian–Albian (Table 5). In the same part, dwarfed specimens of planktonic rotaliporids were also noticed and Blaicher (1973) reported the Albian–Turonian species *Plectorecurvoides alternans*. However, the latter species can be regarded as specific contamination due to tectonic or other phenomena. Foraminiferal assemblages recognized in the upper part of the formation (Sztolnia A, B) contained *Hyperammina gaultina*, *Glomospirella gaultina*, *Ammobaculoides carpathicus*, *Trochammina vocontiana* and other taxa. During re-examination the following species were aditionally recognized: *Trochammina* (= *Ammogloborotalia*) *abrupta*, *Thalmannammina* cf. *anastasiui*. The species *T*. (= *Ammogloborotalia*) *abrupta*, *A*. *carpathicus* and *Verneuilinoides neocomiensis* were regarded as reworked by Malata (in: Oszczypko *et al*., 2004) in a view of the present studies may be autochthonous components of foraminiferal faunas of the Szlachtowa Fm.

Foraminiferal assemblages reported by Blaicher (1973) from the Szlachtowa Fm. of the archive section "Krupianka Stream" resemble those from sections "Sztolnia A, B".

Assemblages of foraminifera of the Szlachtowa Fm. studied in "Krupianka Stream" are similar in specific compositon to assemblages from the same formation recognized by the present authors described above. Taking into account the total stratigraphic ranges of the foraminiferal taxa (Table 5) the possible lower age interval is Berriasian to Albian–Cenomanian. However, the stratigraphic position of the Szlachtowa Fm. suggests an Aptian–Albian age. The presence of *Verneuilinoides graciosus* (Fig. 10S), *Trochammina* cf. *neocomiana*, *Spirillina* sp. and *Trocholina* sp. of Kimmeridgian–Tithonian character in the clasts of thick-bedded sandstone (WP 215a, b) additionally excludes a Middle Jurassic age for the Szlachtowa Fm., postulated by Birkenmajer and Pazdro (1968) and Birkenmajer (1977).

7. The Opaleniec Formation. The stratigraphic ranges of the foraminiferal species found in Sztolnia A: *Dorothia subtrochus* is Barremian–Cenomanian while *Rotalipora* (=*Parathalmanninella*) cf. *appenninica* is Albian–Cenomanian. Thus, the overlapping age is Albian–Cenomanian. Similarly to the section "Sztolnia B", the overlapping range of the youngest taxa is Albian–Cenomanian based on *Gyroidinoides infracretaceus* and *Gavelinella (Berthelina)* cf. *berthelini* (Keller) (Table 6). *Praedorothia ouachensis* whose range is Valanginian–Aptian may suggest reworking.

8. Cenomanian Key Horizon (Hulina Formation in part). These deposits represent the upper sedimentary boundary of the "black flysch" succession in the Małe Pieniny Mts. The boundary between the Opaleniec Fm. and the CKH is transitional, and is represented by dark grey shales with intercalations of red shale. The presence of *Thalmannammina subturbinata*, *Ammosphaeroidina pseudpopauciloculata* and *Parathalmanninella appeninnica* indicates a Late Albian–Early Cenomanian age (Gawor-Biedowa *et al*., 1994).

The uppermost part of the CKH is represented by radiolarites with intercalations of red shale (mouth of Sielski Stream, WP 370), which yielded a typically poor foraminiferal assemblage composed of *Bathysiphon* sp., *Nothia excelsa*, *Hedbergella planispira* and rare radiolarians, not younger than Turonian. The radiolarites are overlain by spotted limestones (sample WP 943) which yielded a rich nannoconid assemblage with *Nannoconus* aff. *minutus* Brönnimann of Hauterivian–Cenomanian range. The Cenomanian age of the CKH is also supported by calcareous nannofossils documented in the spotted limestones in the Sztolnia A section (Fig. 5; see also Oszczypko *et al*., 2004).

9. Malinowa Shale Formation (Turonian–Campanian). In the sections studied mainly the lower part of this formation occurs.

DISCUSSION

In all sections studied the "black flysch" appears in core of the imbricated folds and/or thrust-sheets, whereas the limbs of

Table 6

Stratigraphic occurrence of the microfossils recovered from the Opaleniec Fm. (based on the literature mentioned in the *Biostratigraphy* section in this paper)

Microfossils of the Opaleniec Fm.	Oxfordian	Kimmeridgian	Tithonian	Berriasian	Valanginian	Hauterivian	Barremian	Aptian	Albian	Cenomanian	Turonian
Gavelinella (Berthelina) berthelini									X	X	X
Plectorecurvoides alternans									X	X	X
Globigerinelloides caseyi									X	X	
Parathalmanninella appennininica									X	X	
Meandrospira washitensis									X		
Pseudonodosinella troyeri							X	X	X	X	X
Dorothia subtrochus							X	X	X	X	
Plectorecurvoides irregularis							X	X	X	X	
Cribrostomoides nonioninoides							X	X	X		
Gyroidinoides infracretaceus						X	X	X	X	X	
Praedorothia ouachensis					X	X	X	X			
Thalmannammina neocomiensis				X	X	X	X	X	X	X	
Trochammina (Ammoglob.) abrupta			X	X	X	X	X	X	X	X	
Verneuilinoides neocomiensis			X	X	X	X	X	X	X		
Ammobaculoides carpathicus			X	X	X	X	X	X			
Pseudoreophax cisovnicensis			X	X	X	X	X				
Trochammina annae			X								
Spiroplectammina vicinalis			X								
Bulbobaculites elongatulus			X								
Verneuilinoides kirillae		X	X								
Verneuilinella carpathica		X									
Thalmannammina anastasiui		X									
Spirillina elongata	X	X	X								
Trochammina canningensis	X	X	X								
Lenticulina muensteri	X	X	X	X	X	X	X	X	X	X	X
Colomisphaera cieszynica		X	X	X							
Colomisphaera vogleri					X	X	X	X			

the folds are composed of the Malinowa (Turonian–Campanian) and Jarmuta (Maastrichtian–Paleocene) formations. Locally the Jarmuta Fm. overlies directly the "black flysch". The "black flysch" deposits are limited at the base and top by a condensed sequence of limestone and radiolarite rocks.

The stratigraphic base of the "black flysch" can be represented by strata of Late Jurassic–Early Cretaceous age preserved on the left bank of the Grajcarek Stream at Szczawnica-Zabaniszcze. The youngest strata of this Zabaniszcze succession belong to the Kapuśnica and Wronine formations. with a total thickness of *ca*. 1.5 m. On the basis of dinocysts (Gedl, 2007) the age of these formations is Late Barremian–Early Aptian.

In the Zabaniszcze section the Kapuśnica–Wronine formations are overlain by the Szlachtowa Formation. This formation represents typical "black flysch" composed of thin- to thick-bedded turbiditic sandstones with intercalations of black and dark grey marly mudstone and shale with muscovite flakes. According to geochemical studies, the black shales of the Szlachtowa Fm. can be related to the Early Cretaceous OAE 1 (Wójcik-Tabol and Oszczypko, 2012). This formation passes upwards into a 10 to 16 m-thick packet of light grey spotted shales and marls with pyrite concretions and sideritic limestone intercalations belonging to the Opaleniec Fm.

The claystones and mudstones of the "black flysch" contain both calcareous as well as siliceous (agglutinated) benthic foraminiferal assemblages. The calcareous foraminifera are dominated by nodosarids (*s.l.*). *Lenticulina* ex gr. *ouachensis* Sigal, present in some samples, may be an example of the irrelevance of the Nodosariidae for precise statigraphic designations. This species is characterized by an "annular" umbilical region and elevated sutures similar to *Lenticulina quenstedti* (Gümbel). Both species belong to a group with the same morphology of tests that had several growth optima between the Early Toarcian and Early Cretaceous (Bartenstein, 2000). This fact considerably reduces their stratigraphical significance. The same refers to the genera *Pseudonodosaria*, *Lingulina*, *Dentalina*, and others.

In the material analysed from the Szlachtowa Fm. (Sztolnia A section) three foraminiferal assemblages can be distinguished: the oldest belongs to the Oxfordian/Tithonian, the second one represents the Berriasian–Barremian, and the youngest indicates the Aptian/Albian–Cenomanian (Table 5). Similarly, in the Opaleniec Formation (Table 6): the oldest assemblage belongs to the Oxfordian–Hauterivian, intermediate to the Aptian, and the youngest to the Albian–Cenomanian.

Between the top of the "black flysch" and the variegated shales of the Malinowa Fm. (Turonian–Campanian–?Maastrichtian) a sequence of strata, referred to by Sikora (1962, 1971*a*, *b*) as the "Cenomanian Key Horizon" (CKH) is developed. The CKH is represented by green and black shales with green and red radiolarites and spotted limestones at the top. The radiolarites are intercalated with red shales containing a Cenomanian microfauna. Cenomanian calcareous nannoplankton were recognized in the overlying spotted limestones both in the Sztolnia A section (see also Golonka and Sikora, 1981; Oszczypko *et al*., 2004) and at the WP 370 site (Fig. 1B). According to geochemical studies, the black shale intercalations in CKH (Sztolnia A, B, C sections) can be related to the Late Cretaceous OAE 2 (Wójcik-Tabol and Oszczypko, 2012).

The results presented, in general, support Sikora's (1962, 1971*b*) view on the Mid-Late Cretaceous age of the "black flysch" succession in the Małe Pieniny Mts. (see also

Oszczypko *et al.*, 2004). The results of these studies support also the geological observations indicating lithofacies interfingering of the upper part of the Sztolnia and Opaleniec lithofacies. Our studies support also the previous supposition of Sikora (1962, 1971*a*, *b*) that the base of the "black flysch" is probably composed of a radiolarite/carbonate condensed sequence, known from the Zabaniszcze (A and C) sections.

The occurrence of uppermost Jurassic/Early Cretaceous species of foraminifera in the Szlachtowa and Opaleniec formations may suggest either their possessing wider stratigraphic ranges than previously known, or reworking of sediments from the shallower part of the basin, or perhaps the emergence of morphological forms typical of certain type of environment (e.g., oxygen-depleted environments).

The occurrence of reworked assemblages of foraminifera due to erosion of the shallower parts of the basin seems most probable. Depending on the energy of the gravity-driven currents, small particles, clasts of different sizes as well as olistholiths may be eroded. However, olistholiths have not yet been identified in the deposits of the Szlachtowa and Opaleniec formations studied.

The current dispute concerning the age of the "black flysch" is reminiscent of the discussion in the 1960s (see e.g., Sikora, 1962; Książkiewicz, 1977). The supporters of the Cretaceous age of these deposits were accused of incorrect species determinations, while sample contaminations was also involved. Supporters of a Middle Jurassic age for the "black flysch" do not state why identical assemblages of foraminifera have been found in various profiles of the Grajcarek succession, where the "washed out" microfossils may came from and why there is no contamination of the Turonian–Campanian assemblages, abundant in the variegated marls of the Jaworki Formation of the PKB or the red shales of the Malinowa Formation of the Grajcarek succession. In the views of our adversaries, there is no reflection on the geological position of the Szlachtowa and Opaleniec formations in the Grajcarek succession. These interpretations also do not take into account the known cases of reworked assemblages in the flysch of the Outer Carpathians (e.g., Magura and Krosno formations; see Oszczypko *et al*., 1999). Reworked assemblages are also known from other orogenic belts such as the "Crete Nero"/Cilento Cilento Flysch in the Southern Apennines (see Cieszkowski *et al.*, 1994 and references therein) as well as from deep-water oceanic sections (Kaminski *et al*., 1992 and references herein). A recent reconsideration of the age of the Outer Dinaride flysch deposits in Slovenia, Croatia, Bosnia-Herzegovina and Montenegro, due to the redeposition, is given by Mikes *et al*. (2008).

Assumption of a Middle Jurassic age for the Szlachtowa and Opaleniec formations is leading to the question: where did the Upper Jurassic–Lower Cretaceous deposits dissapear? Possible solutions to these dilemmas can be found through tectono-sedimentary analysis of the initial stages of development of the Grajcarek sub-Basin.

GEOTECTONIC IMPLICATIONS

The Grajcarek succession was deposited in the southern part of the Magura Basin (Birkenmajer, 1977, 1986; see also Oszczypko, 2006). The opening of the Magura Basin probably took place during the Early/Middle Jurassic. During the Late Jurassic to Early Cretaceous this basin was occupied by deep-water, condensed deposits of the radiolarite/carbonate sequence, known from the Zabaniszcze sections. A round the Late Jurassic–Early Cretaceous boundary the southern periphery of the Magura and the Czorsztyn sedimentary areas were affected by the Neo-Cimmerian extensional gravitational faulting (Birkenmajer, 1986, 1988) and formation of synsedimentary breccia (Wierzbowski and Remane, 1992; Golonka *et al*., 2003). As a result of these tectonic movements the major part of the Czorsztyn sedimentary area was uplifted and eroded between the Berriasian and the Aptian/Albian boudary (Birkenmajer, 1986, 1988; Golonka *et al*., 2003). These extensional tectonics were accompanied by local intra-plate volcanism (Birkenmajer and Lorenc, 2008; Krobicki *et al*., 2008; Spišak *et al*., 2011).

At the Aptian/Albian boundary the Neo-Cimmerian movements might had been manifested, in the southern part of the Magura Basin, by shallowing and by the beginning of sedimentation of the Szlachtowa Formation. Erosion of the emerged part of the Czorsztyn succession partly supplied the material for the Szlachtowa sediments. These sediments accumulated in the form of littoral bank, rich in remains of fragments of crinoids and macrofauna, and then were transported to deeper parts of the basin by gravity-driven currents. The turbidite currents probably also eroded the older (Tithonian/Berriasian) fine-grained deposits of the Grajcarek succession.

The other sedimentary components of the Szlachtowa Fm. derived from the eroded, emerged epizonal metamorphic rocks, which provided mica flakes and numerous siliciclastic grains.

The Albian global rise sea level was marked by deepening of the southern part of the Magura Basin and by the transition from lithofacies of the "black flysch" (Szlachtowa Fm.) to the green hemipelagic shales of the Opaleniec Formation. This was accompanied by an increase in radiolaria that reached its maximum during sedimentation of the Cenomanian Key Horizon deposits. Further deepening of the basin, below the local CCD, resulted in sedimentation of hemipelagic red shales (CORB) with intercalations of thin-bedded turbidites of the Malinowa Shale Fm. (Turonian–Campanian). A similar transition from the "black flysch" deposits of the "Gault flysch" (Hauterivian–Albian) to the Cenomanian–Turonian red shales and marls is known from the entire margin of the NW Tethys. Such a succession was reported from the Moravian sector of the Magura Nappe (Švabenická *et al.*, 1997) and the Rhenodanubian Flysch Zone of Lower Austria (Schnabel, 1992). In the Małe Pieniny Mts., the hemipelagites of the Malinowa Shale Formation were followed by coarse-grained conglomerates, rich in PKB material and exotic blocks and clasts, as well as by thick-bedded turbidites of the Jarmuta Formation of Maastrichtian/Paleocene age.

The Early Cretaceous flysch deposits crop out along all the Alpine Chains of Western, Central and Eastern Europe for more than 7000 km from the Gibraltar Arc to the Balkans (Maghrebides, Apennines, Alps, Dinarides, Hellenides, Carpathians and Balkans, see Puglisi, 2009). In the course of the Late Cretaceous re-organization of the plates, all these deposits experienced considerable tectonic deformation.

Also, very similar deposits to the Early/Middle Cretaceous Grajcarek succession of the Małe Pieniny Mts. have been recognized in the northern part of the PKB, near Khust and Svalava (Ukrainian Carpathians; see Rozumeyko and Venglinsky, 1989).

CONCLUSIONS

1. In all the sections studied of the Grajcarek thrust-sheets in the Małe Pieniny Mts. the "black flysch" appears in the core of imbricated folds or thrust-sheets, whereas the limbs are composed of Upper Cretaceous deposits.

2. Biostratigraphical investigations have revealed a similar type and sequence of microfaunal assemblages in all the sections studied. It should be stressed that significant redeposition of ?Jurassic calcareous benthic foraminifera, calcareous nannoplankton, and elements of crinoids as well as of Late Jurassic–Early Cretaceous agglutinated foraminifera have been observed in the microfaunal assemblages recovered from the black flysch turbiditic sequences.

3. The Cretaceous age (Aptian/Albian–?Cenomanian) of the "black flysch" is indicated both by the geological setting and by the presence of specific agglutinated foraminifera and microfacies data.

4. The transitional beds between the "black flysch" and the Upper Cretaceous red shales are composed of green and black, bituminous shales with manganese oxide coatings, red and green radiolarites with pyrite framboide, cherty limestones, and finally very thin layers of dark, non-calcareous shales (CKH). In the shale intercalations within the red and green radiolarites of the CKH, Cenomanian foraminiferal assemblages have been documented while the cherty limestones yielded Albian–Cenomanian calcareous nannoplankton. The green shales with manganese coatings (CKH) contain abundant radiolaria in various states of preservation and finally, the red shales of Malinowa Fm. yield assemblages with the characteristic agglutinated taxa *Tritaxia gaultina*, *Uvigerinammina jankoi*, *Spiroplectinella costata* and *Caudammina gigantea*, indicating a Turonian–Campanian age of deposition. Such a sequence of deposits is typical of the Outer Carpathian and other Tethyan basins and records the global Mid-Cretaceous phenomena in the world ocean, followed by the Cretaceous Oceanic Red Beds.

Acknowledgments. This research was mainly financed by Jagiellonian University scientific funds (K/ZDS/001933) and partly by a research project of the Polish Ministry of Science and Higher Education (K/PBW/000641). The Authors thank Prof. M. Kaminski (Fing Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia), Prof. D. Plašienka (Komensky University, Bratislava) and Prof. A. Wierzbowski (Warsaw University) and two anonymous reviewers for their constructive and critical comments on the manuscript.

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