

GEOLOGY OF THE MAGURA NAPPE IN THE OSIELEC AREA WITH EMPHASIS ON AN EOCENE OLISTOSTROME WITH METABASITE OLISTOLITHS (OUTER CARPATHIANS, POLAND)

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Abstract: The Magura Nappe in the Polish sector of the Outer Carpathians consists of four tectonic subunits characterized by differing development of facies. From the south to the north, they include the Siary, Rača, Bys-trica and Krynica subunits. The sedimentary succession in the Rača Subunit in the vicinity of the village of Osielec is composed of Campanian–Palaeogene flysch deposited in the Magura Basin. In this succession, the Middle Eocene Pasierbiec Sandstone Fm consists of thick-bedded sandstones and conglomerates with occasional intercalations of thin-bedded shale-sandstone flysch. Within the Pasierbiec Sandstone Fm at Osielec there is an olistostrome, rich in pebbles and cobbles of exotic rocks. In addition, large blocks of Neoproterozoic metabasites and boulders of Palaeogene organogenic limestones were found. The discovery of metabasites raised the possibility that the rocks in question could be evidence of supposed oceanic crust in the basement of the Magura sedimentary basin, because of the suggestion that they represent the Alpine orogenic cycle. This concept was abandoned when investigations of the absolute age of the metabasites gave a date of ca. 600 Ma. In the Osielec area, there are two tectonic thrust sheets in the Rača Subunit, namely the Osielczyk Thrust Sheet in the north and the Bystra Thrust Sheet in the south; they are folded and cut by a transverse system of strike-slip and oblique faults. The Osielczyk Thrust Sheet was overthrust northwards on to the Siary Subunit.

Key words: Magura Nappe, Rača Subunit, Late Cretaceous–Palaeogene, lithostratigraphy, tectonics, olistostrome, olistoliths, metabasite.

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INTRODUCTION

The idea of a detailed geological investigation of the Magura Nappe in the Babia Góra region, beginning in the vicinity of the village of Osielec, was motivated by the interesting presentations of the geological structure of this area by Książkiewicz (1958, 1966; and in Burtan and Szymakowska, 1966) and the very important study of fold tectonics of the Babia Góra region that was presented by Aleksandrowski (1985). A brief description of the Magura Fm sandstones, exposed in the quarry in the southern part of Osielec village, was presented by Cieszkowski (1985). The geology of Osielec village was presented by Wójcik and Rączkowski (1994), in the explanations to the Osielec Sheet of the Detailed Geological Map of Poland on a scale 1:50000, but in relation to the results of Książkiewicz did not make significant amendments. The geological interpre-

tation by Książkiewicz, presented on the map edited by Burtan and Szymakowska (1966), was adopted in a new version of the Osielec Sheet (Książkiewicz *et al.*, 2017). The present authors were particularly interested in the tectonics of the so-called “Osielec Skiba” – “skiba” in Polish geological nomenclature is a large thrust sheet with a complex internal structure – and the lithostratigraphic position and sedimentary features of the Pasierbiec Sandstone, especially well developed there. These deposits had been mentioned by Uhlig (1888) and described first as sandstones rich in nummulites. Bieda (1946) described them under the name “Pasierbiec Sandstone” and determined their age as Middle Eocene on the basis of large foraminifera. During the course of studies of the Magura Nappe in the Beskid Makowski (Średni) and Beskid Żywiecki (Wysoki) ranges, investigations

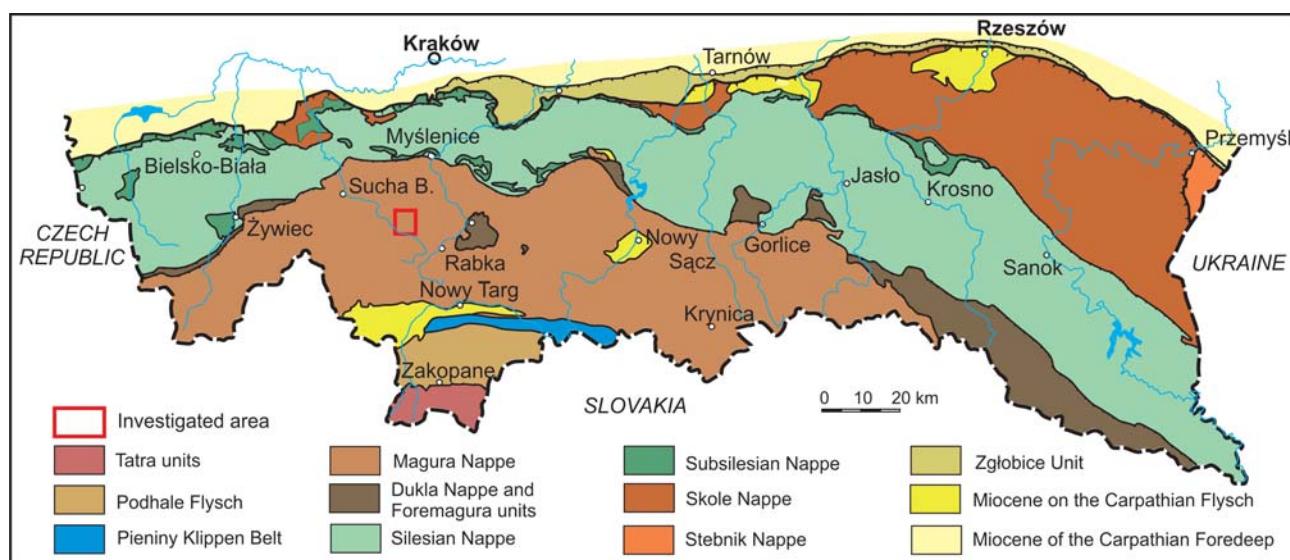


Fig. 1. Geological sketch map of the Polish sector of the Outer Carpathians, showing location of the study area (Chodyń and Cieszkowski based on Żytko *et al.*, 1989, modified).

of the Pasierbiec Sandstone were continued by Książkiewicz (1948, 1951a, b, 1958, 1962, 1966) together with Sikora and Żytko (1956, 1960), Wieser (1966) and Bieda *et al.* (1967). In the Pasierbiec Sandstone Fm, a metabasite block was found at Osielec by Książkiewicz during geological mapping and then described in detail by Wieser (1952). Wieser considered it to be an albite amphibolite or a hornblende prasinite and regarded it as an ophiolite. Wieser's interpretation did not receive much comment in the geological literature until now; this occurrence of metabasites in the Carpathian flysch is unique and important and recently became a subject of discussion. As well, the presence of debris flow deposits and chaotically deformed flysch layers observed during preliminary field reconnaissance encouraged the present authors to expand existing geological knowledge about the Osielec area and to collect new data on the olistostromes and olistoliths, which have been systematically investigated in the Outer Carpathians for several years (e.g., Cieszkowski *et al.*, 2009, 2012; Waškowska and Cieszkowski, 2014; Golonka *et al.*, 2015).

Geological studies at Osielec have been continued by geologists of the Jagiellonian University since 2009. Kysiak (2010a) pursued his master's thesis on the geology of Osielec (map in Fig. 1) and found new outcrops with large blocks of metabasite. The preliminary results of studies on these metabasite blocks and their geological position were presented at a number of conferences (Cieszkowski *et al.*, 2010, 2015b; Kysiak, 2010b). However, some geological problems in the Osielec area remained unresolved and Cieszkowski and Szczęch continued their field investigations, with special attention to detailed geological mapping. Together with Kysiak, they produced a new detailed geological map (Fig. 2). Remote sensing data were very helpful in the final interpretation of this map. At the same time, Wolska (see Anczkiewicz *et al.*, 2016) examined petrological and geochemical aspects of the exotic rocks from Osielec.

GEOLOGICAL SETTING

Osielec village is located on the southern slopes of the Beskid Makowski Mts, on the Skawa river, between the towns of Jordanów and Maków Podhalański, about 60 km SSW of Kraków (Fig. 1). The location is geologically in the Outer Carpathians, also called the Flysch Carpathians (Mahel', 1974; Książkiewicz, 1977a). The Flysch Carpathians consist of several nappes overthrust one upon another and all together transported over the Miocene deposits of the Carpathian Foredeep, on the southern margin of the North European Platform (Książkiewicz, 1972, 1977a; Golonka *et al.*, 2003, 2005; Oszczytko, 2006; Ślęczka *et al.*, 2006). In the Polish sector of the Outer Carpathians, the Magura Nappe is the largest among the flysch nappes (Książkiewicz, 1977a; Oszczytko, 1992, 2006; Golonka *et al.*, 2003). It is subdivided into four subunits (Koszarski *et al.*, 1974; Cieszkowski *et al.*, 1985; Oszczytko, 1992). Each subunit displays its own typical sedimentary sequence, Late Cretaceous to Palaeogene in age, which consists of several lithostratigraphic units. The sequences were deposited in different zones of the Magura Basin. From north to south, they are the Krynica, Bystrica, Rača and Siary subunits. Lithostratigraphic units in the Magura Nappe were partly formalized by Birkenmajer and Oszczytko (1989), Oszczytko (1992), and Oszczytko *et al.* (2005). Formalization of lithographic units of the northern zone of the Magura Nappe was proposed by Cieszkowski *et al.* (2006) and Golonka *et al.* (2013). In the area investigated, the Rača and Siary subunits are present. The "Osielec Skiba" (Książkiewicz 1958, 1966) of the Rača Subunit can be subdivided into two thrust sheets. The sedimentary successions in each of these thrust sheets are distinctly different (Fig. 3). In the northern thrust sheet, the Pasierbiec Sandstone Fm is more than 200 m thick and contains olistostromes with large metabasite olistoliths.

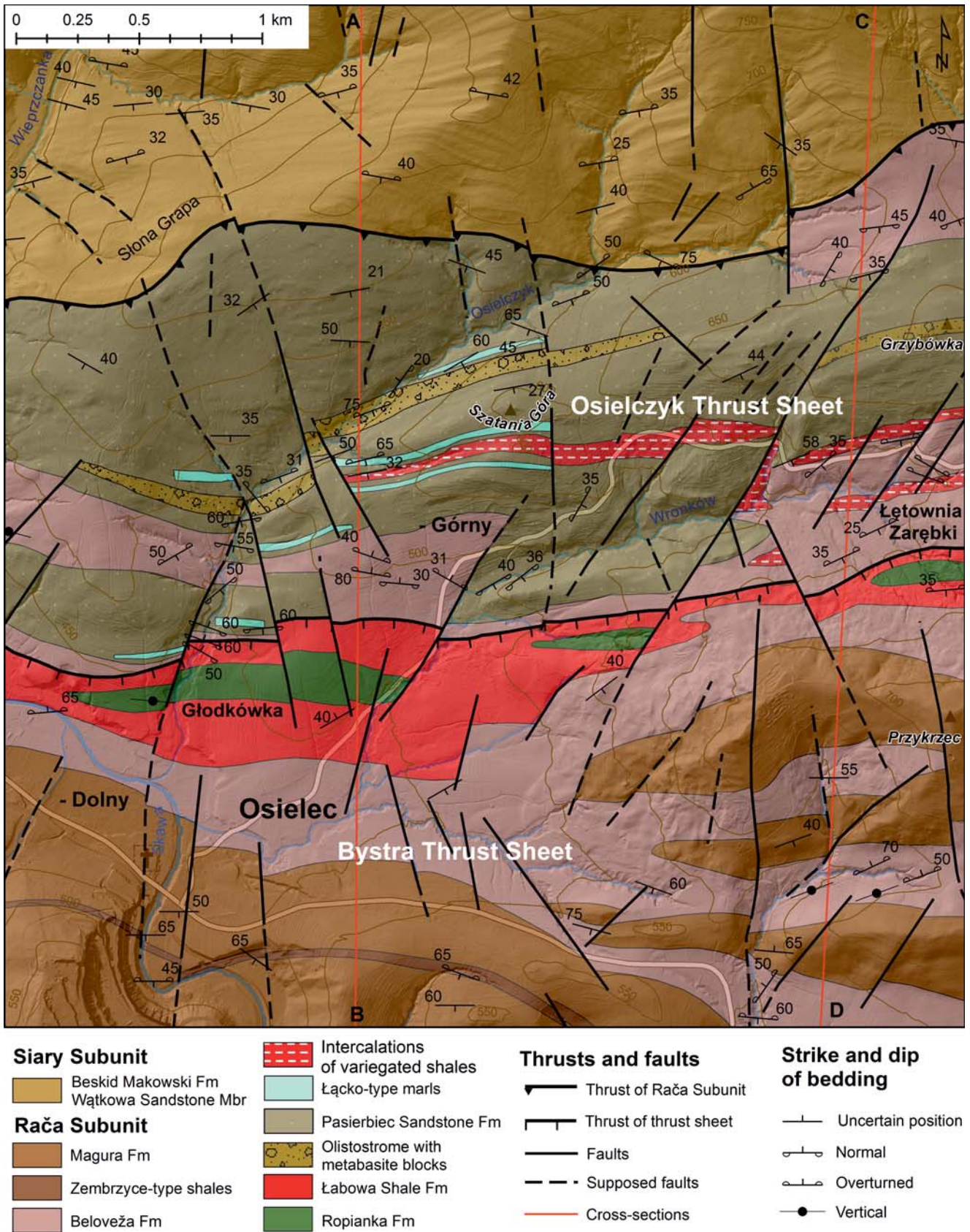


Fig. 2. Geological map of the study area.

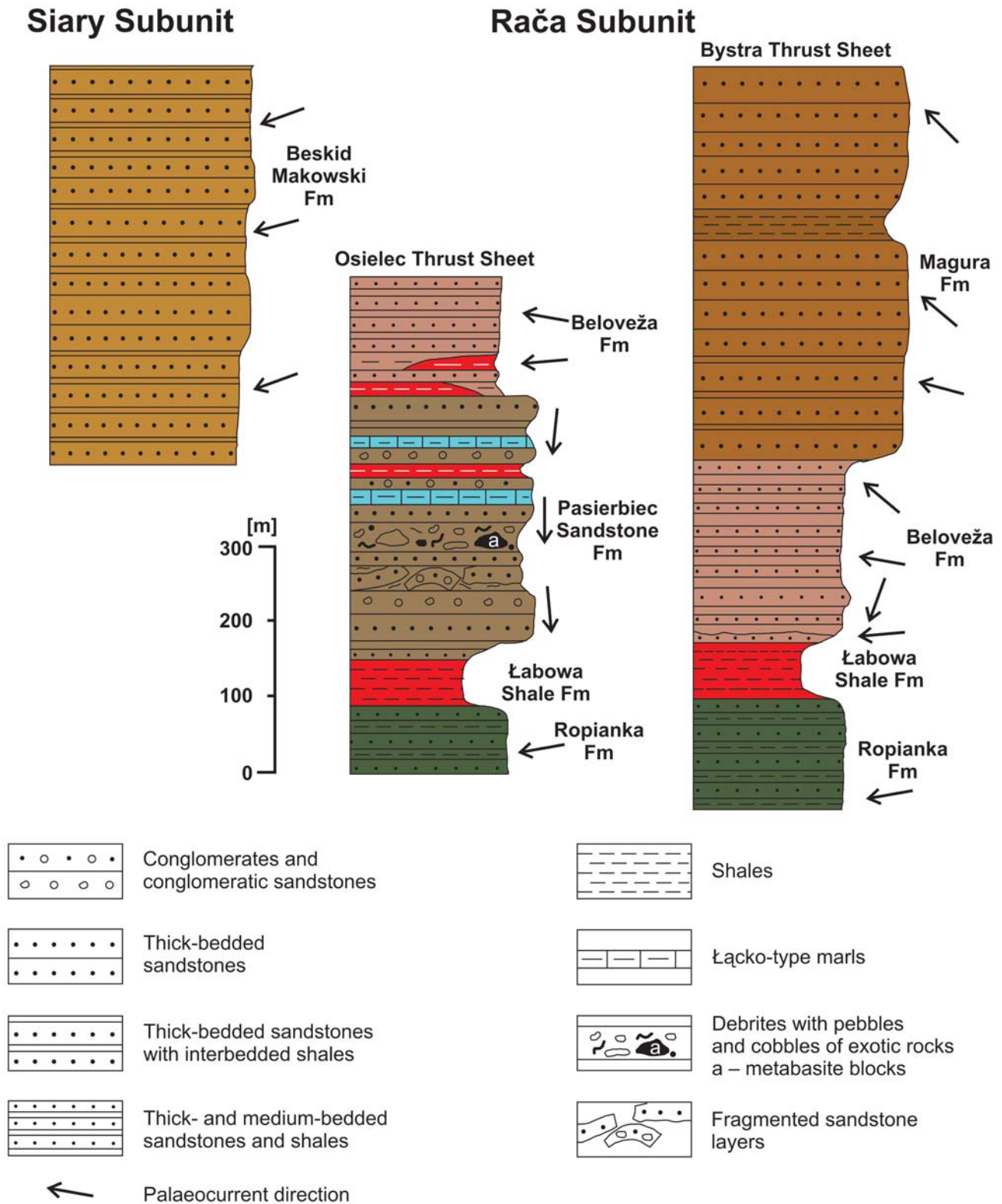


Fig. 3. Lithostratigraphic logs of the Magura Series in the study area.

ANALYTICAL METHODS

The study area was investigated by using the traditional methods of geological mapping. The positions of all observation points, sampling sites and photographs were speci-

fied with the aid of a Global Positioning System (GPS) device and the data were stored in a geodata base. Remote sensing data were analysed using a high-resolution digital elevation model (DEM) by means of ArcMap10.3 software. It was especially helpful in areas covered by forest and

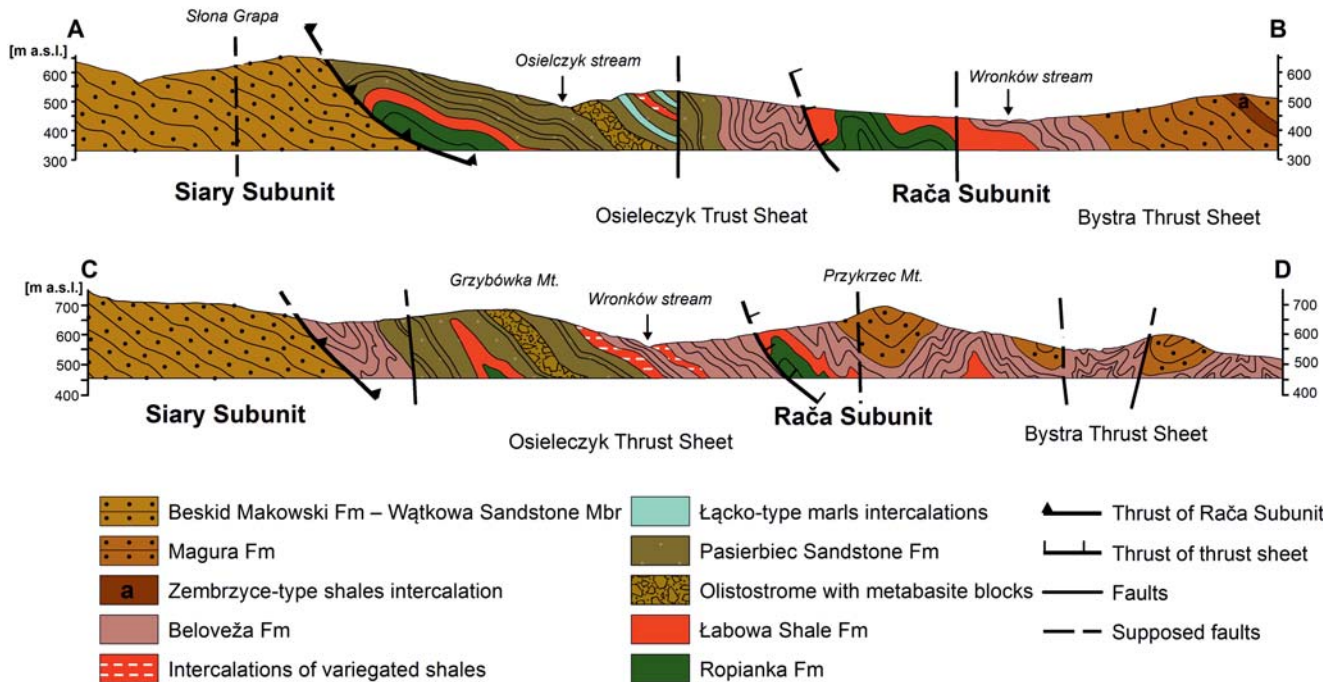


Fig. 4. Geological cross-sections of the Magura Nappe in the study area.

where the ground surface had not been modified by agriculture. In these places, the stratification is clearly visible on the DEM. Parts of faults and thrusts were detected on the DEM by applying morpholineament methods. Microscopic studies were performed using a NIKON YM-EPI Eclipse E600POL optical microscope. Microphotographic documentation was carried out with a CANON EOS 40D camera.

STRATIGRAPHY

In the vicinity of Osielec, the Rača and Siary subunits of the Magura Nappe are present (Figs 2–4). The Siary Subunit occupies only the northernmost part of study area and consists of the Late Eocene–Oligocene Wątkowa Sandstone Member of the Beskid Makowski Formation. The sedimentary succession of the Rača Subunit comprises five lithostratigraphic formations, Late Cretaceous to Palaeogene in age and mainly developed as a flysch facies. From the bottom to the top, they include the Ropianka Fm, the Łabowa Shale Fm, the Pasierbiec Sandstone Fm, the Beloveža Fm, and the Magura Fm (Fig. 3).

Ropianka Formation (Campanian–Palaeogene)

The Ropianka Formation, previously also known as the Inoceranian Beds (Fig. 5A), consists of thin- and medium-bedded sandstones, intercalated with shales. The sandstone layers are usually up to several centimetres and occasionally up to 50 cm thick. The sandstones are muscovitic, grey coloured, fine-grained, and in the thicker layers medium- to coarse-grained. Parallel lamination and cross-lamination, often convolute (Tbcde, Tbc_{conv}de or Tcde Bouma sequences) are common, but in the medium- or thick-bedded lay-

ers, the lower part is massive and normally graded (Tabcde, Tabc_{conv}de). The sandstones are well sorted and mainly consist of quartz and muscovite, with the addition of feldspars, biotite and plant detritus, and occasionally rare glauconite. Muscovite, usually with an admixture of coalified plant detritus, is concentrated on the lamination surfaces. Grains are bounded with silica-carbonate cement. Current marks and trace fossils are present on the lower bedding surfaces. The former indicate palaeocurrents from the east. The shales, with thicknesses of a few to several centimetres, are represented by grey, light grey and greenish mudstones or muddy claystones. The grey-coloured shales are to different degrees marly and the greenish shales are noncalcareous. The shales are often rich in ichnofossils. At Osielec, the exposed thickness of the Ropianka Fm reaches about 100 m, as reported by Książkiewicz (1962). The Ropianka Fm in the Osielec and adjacent areas is dated as upper Late Cretaceous–Paleocene on the basis of foraminiferal assemblages (Jednorowska, 1966; Geroch *et al.*, 1967; Malata, 1981; Wójcik and Rączkowski, 1994).

Łabowa Shale Formation (Early–Middle Eocene)

The Łabowa Shale Formation (Fig. 5B) is developed as a complex of muddy or clayey variegated shales, mainly red and subordinately green. The proportion of the green shales increases and of intercalations of thin and very thin-bedded fine-grained greenish sandstones increase up the section. The shales of the Łabowa Shale Fm are massive when fresh, flaky and fissile when weathered. According to micropaleontological data, the Łabowa Shale Fm at Osielec and in the adjacent areas is dated as latest Paleocene–Middle Eocene (Bieda, 1966; Jednorowska, 1966; Geroch *et al.*, 1967; Malata, 1981; Boryslawski, 1985; Wójcik and Rączkowski,



Fig. 5. Outcrops of the deposits of the Magura Nappe in the study area. **A.** Ropianka Fm. **B.** Variegated shales of the Łabowa Shale Fm. **C.** Thick-bedded sandstones of the Pasierbiec Sandstone Fm with flute casts, showing a palaeocurrent direction from the north. **D.** Thick-bedded sandstones and conglomerates of the Pasierbiec Sandstone Fm. **E.** Chaotic olistostrome deposits with fragmented and disturbed, thick-bedded sandstones of the Pasierbiec Sandstone Fm. **F.** Thick-bedded Łacko Marl-like marls in the Pasierbiec Sandstone Fm. **G.** Sandstones and shales of the Beloveža Formation. **H.** Thick-bedded sandstones of the Magura Fm.

1994; Cieszkowski *et al.*, 2015b). In some papers, only Early Eocene taxa were observed (e.g., Bieda, 1966; Malata, 1981).

Beloveža Formation (Middle–Late Eocene)

The Beloveža Formation (Fig. 5G), previously called the Hieroglyphic Beds in this region (e.g., Książkiewicz, 1958, 1966), is dominated by a thin-bedded sandstone-shale succession. Usually, shales predominate over sandstones. The sandstones are grey-greenish, fine grained, thin-bedded, but up the section medium-bedded or single thick-bedded, fine-, medium- and rarely coarse-grained sandstones also occur. The sandstones show parallel, planar and subordinate ripple-cross-lamination. The Bouma intervals T_{bc}d and T_{cd} are common, but occasionally T_{abc}d also occurs. Small mechanoglyphs and trace fossils are common. The sandstones are composed mainly of quartz, with a low feldspar content and varying amounts of glauconite and muscovite. The cement is siliceous, siliceous-clayey or siliceous-carbonate. Shales are represented by grey-greenish, grey or dark grey-coloured, clayey or marly mudstones.

In the thin- and medium-bedded sandstones of the Beloveža Fm, palaeocurrent directions from the east (azimuths about 260–265°) predominate, in accordance with the data from this region by Książkiewicz (1962). A single case of transport from the NNE was noted in an bed of glauconitic sandstone, about 0.9 m thick, in the eastern part of Osielec village. Książkiewicz (1962) reported palaeocurrent directions from the ESE in the uppermost part of the Beloveža Fm, where the first intercalations of thick-bedded sandstones typical of the Magura Fm were recorded. The Beloveža Fm is dated to the Middle–Late Eocene (Jednorowska, 1966; Książkiewicz, 1966, 1974; Geroch *et al.*, 1967; Malata, 1981; Borysławski, 1985; Wójcik and Rączkowski, 1994; Golonka and Waškowska, 2012). Middle Eocene large foraminifera were described by Bieda (Bieda and Książkiewicz, 1958) from Osielec and from Wieprzec village neighbouring to Osielec in the west (Bieda, 1966). A Late Eocene assemblage of small calcareous foraminifera, also from Wieprzec, was determined by Blaicher (1961).

Pasierbiec Sandstone Formation (Middle Eocene)

The Pasierbiec Sandstone Formation (Fig. 5D) is a series of thick-bedded sandstones, conglomeratic sandstones and conglomerates, with occasional breccias, with intercalations of thin-bedded Beloveža Fm-like shale-sandstone deposits as well as occasional layers of marls, representing the Łącko (Zlin) Marl lithotype (Fig. 5F). This marl lithotype is mostly typical of the Bystrica Fm of the Bystrica Subunit (e.g., Oszczytko, 1991). At Osielec, the thick-bedded detrital deposits are represented by two lithotypes, which were considered in the past as separate lithostratigraphic units – the Pasierbiec Sandstone (in fact, sandstones and conglomerates) and the Osielec Sandstone. This second one was distinguished by Książkiewicz (1966) as a fine-grained variety of the Pasierbiec Sandstone.

The Pasierbiec Sandstone lithotype forms thick-bedded layers, 0.5–2.0 m, occasionally up to 3.0 m in thickness. The layers are normally graded, coarse-grained or conglomer-

atic at the base. There are also intercalations of coarser conglomerates with pebbles of exotic rocks, 2–10 cm in diameter and occasionally larger (Fig. 6A–D). The sandstones and conglomerates are polymictic (cf. Fig. 8A, B), composed mainly of quartz, transparent, smoky and milky, with an admixture of feldspar, some muscovite and glauconite. There are also different lithoclasts of limestones, cherts, red and green radiolarites, mudstones and claystones, granitoids, metabasites, amphibolitic and micaceous gneisses, phyllites as well as chloritic, sericitic and muscovitic schists. The components of the conglomerates are not weathered, and usually poorly rounded or angular, showing that the transportation of the clastic material was rather short-lived. In the coarse sandstones and fine conglomerates, large foraminifera (Fig. 6D, H), mainly nummulites, can rarely be observed. The cement of the sandstones and conglomerates is carbonate or silicic-carbonate.

Microscopic examination of the Pasierbiec Sandstone showed that these detrital deposits are medium- to coarse-grained, with the mean size of mineral grains from 0.2 mm to 0.5 mm (locally up to 0.9 mm). The grains are subrounded (after Pettijohn, 1975) and the sandstones are moderately to very poorly sorted (Fig. 8A, B).

Quartz is the dominant mineral. It commonly occurs as ‘mosaic’ and undulose grains (Fig. 8B). The feldspar grains (orthoclase perthite, plagioclase) occasionally are strongly altered (sericitized). Phyllosilicates fragments occur as flakes in subordinate amounts. Grains of white mica are more common than grains of chlorite and glauconite (Fig. 8A).

Lithoclast grains (Fig. 8) are represented mainly by metamorphic rocks, showing low- and medium-grade, regional metamorphism (gneisses, granitic gneisses, slates/phyllites, schists (Fig. 8B) and organogenic limestones (Fig. 8A). Lithoclasts of magmatic rocks (both felsic and mafic) also occur, including granites, metabasites, and volcanic rocks. Other rock fragments, namely siliceous rocks (Fig. 8B), mudstones, medium- and fine-grained sandstones, are less common. The Pasierbiec Sandstone displays predominantly the contact type of carbonate cement (Fig. 8A); locally the basal type of cement is also observed (Fig. 8B).

The Osielec Sandstone lithotype forms medium and thick beds. The sandstones are light grey and grey-greenish, fine- and medium-grained, especially characterized by a considerable amount of glauconite. Quartz predominates in the mineral composition of the sandstones, besides feldspar, muscovite and various admixture of glauconite, often in large grains. The sandstones are massive, but in the upper parts of beds, parallel lamination and/or cross-lamination often occur. In some beds, extensive convolute lamination is present.

In the Pasierbiec Fm, the sandstone beds form packages, which are from a few to a dozen metres thick. The sandstone layers of both lithotypes typical of the Pasierbiec Fm are intercalated with greenish shales, rarely with dark grey or brown shales. The thickest beds display amalgamation. Some sandstone packages consist of the Pasierbiec Sandstone lithotype and some of the Osielec Sandstone lithotype and combinations of both types. In some beds, the lower part consists of the Pasierbiec Sandstone lithotype and it passes up into the Osielec Sandstone lithotype. The

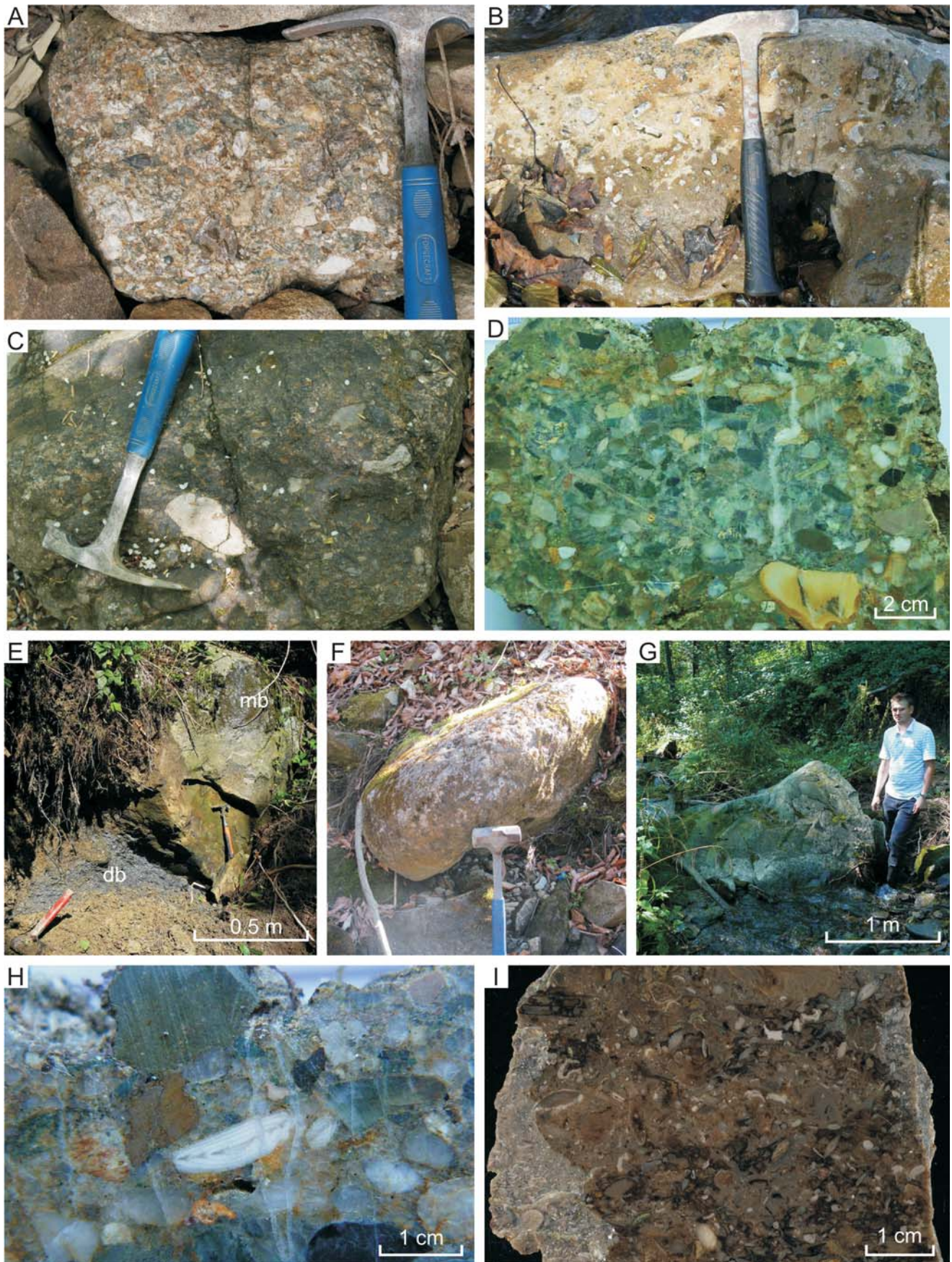


Fig. 6. Deposits of the Pasierbiec Sandstone Fm. **A–D.** Conglomerates and conglomeratic sandstones. **E.** Metabasite block (mb) within debrites (db). **F.** Organogenic limestone bolder. **G.** Tomasz Kysiak, next to metabasite blocks. **H.** Nummulites in fine conglomerate. **I.** Polished fragment of organogenic limestone rich in fossils



Fig. 7. View of the Osielec quarry with thick-bedded sandstones of the Magura Fm.

sandstone packages are intercalated with flysch packages, which are 2–8 m thick and developed in Beloveža Fm-like facies. Locally, thick-bedded sandstones, usually of the Osielec sandstone lithotype, 0.5–1.2 m in thickness, are intercalated with the Łącko Marl lithotype (Fig. 5F), 1.5–3.0 m thick, which usually passes toward the top into massive, light grey marlstone. Książkiewicz (1966) noticed brown cherts with radiolarians at the top of some marls of this type.

In the thick-bedded sandstones of the Pasierbiec Sandstone Fm at Osielec, several measurements of palaeocurrent directions indicate supply of the clastic material from the north (see Fig. 3), as noted by Książkiewicz (1962). In the Rača Subunit, in the north-eastern part of the adjacent Beskid Żywiecki mountain range, palaeocurrent directions from the N, NNW and NW were recorded, while in the Siary Subunit located to north of investigated area, palaeocurrent directions from the N are present (Książkiewicz 1962). Studies of large foraminifers from Osielec and the villages of Wieprzec and Łętownia to the east allowed the determination of a Middle Eocene age for the Pasierbiec Sandstone Fm (Bieda and Książkiewicz, 1958; Bieda, 1966). Similar ages were obtained from investigations of small foraminifera (Jednorowska, 1966; Malata, 1981; Cieszkowski *et al.*, 2015b).

Magura Formation (Late Eocene–Oligocene)

The Magura Formation (Fig. 5H) consists of massive, thick-bedded sandstones, usually interbedded with thin shale layers. The sandstones, representing the micaceous Magura Sandstone lithotype, are characterized by beds dominantly 0.5–2.0 m thick, locally amalgamated and up to 5.0 m thick. The sandstones are grey, light grey or grey-bluish when fresh, fine- and medium-grained, occasionally

coarse-grained in the lower parts of beds. Usually, they are massive and poorly sorted in the lower parts. The top parts of beds are commonly parallel-laminated or cross-laminated, rarely wavy-laminated; the Bouma intervals Ta_{0bc} , Ta_{0c} , Ta_{1bc} , and Ta_{1bcd} may be present. In some thick sandstone beds, large-scale cross-bedding was observed. Load casts are present occasionally in the basal parts of beds. Also trace fossils, mostly *Scolicia*, were found. The sandstones are composed of quartz, feldspar, muscovite, chlorite, occasional biotite, and lithoclasts of mica schists, crumbs of igneous rock, quartzite and carbonate rocks in places. Quartz is the main component and muscovite is enriched on lamina surfaces, often with variable amounts of plant detritus; the sandstones contain also clasts of pelitic rocks and occasionally grains of coal. The cement is carbonate, silica-carbonate with an admixture of clayey or ferrous material. The sandstones are interbedded with shales and thin packages of thin-bedded sandstones and shales, 0.5–2.0 m thick. The shales are made up of mainly grey-greenish or brownish carbonates, to a lesser extent mudstones and sandy mudstones. In the lower part of the Magura Formation, shale intercalations are more frequent and thicker. There are also single layers of shales, up to 1 m thick. In the southern part of the Osielec village, there is a complex of thick-bedded massive, grey, grey-greenish marly mudstone shales interbedded with sandstones, several tens of metres thick; they are similar to strata that are characteristic for the Zembrzyce Shale Member facies, known from the Siary Subunit of the Magura Nappe. The sandstones are medium- and thick-bedded, grey or grey-greenish, fine- and medium-grained; in macroscopic view, they are similar to the thick-bedded sandstones described above. They are composed of quartz, feldspars, muscovite and glauconite. For this lithotype, a high frequency of glauconite is ty-

pical. In the southern part of the village Osielec, the Magura Formation builds up the highest peaks and is very well exposed in the large Osielec quarry, located on the eastern slope of Łysa Góra Mt. (Fig. 7). Flute and groove casts at the bottom of the layers indicate a transport direction of the material from the SE and ESE. In the lowermost part of the formation, where thin intercalations of shale-sandstone packages similar to these of the Beloveža Fm and shale layers similar to those of the Zembrzyce Member of the Beskid Makowski Fm occur, there is evidence of palaeotransport from the E. In the Beskid Żywiecki mountain range, directions from the SE and ESE, and occasionally from the S and E predominate (Książkiewicz, 1962). In the lower part of the Magura Fm in Osielec Quarry, the microfauna studied by Malata (see Cieszkowski, 1985) indicated a Late Eocene age. Other micropalaeontological investigations of foraminifera and calcareous nannoplankton point to the Late Eocene, but in some cases possibly the Oligocene (Jednorowska, 1966; Geroch *et al.*, 1967; Wójcik and Rączkowski, 1994). The Oligocene age of the Magura Fm finally was confirmed by the investigation of nannoplankton from the nearby quarry at Tenczyn (Oszczypko-Clowes, 2001).

OLISTOSTROME

At Osielec, the olistostrome is well exposed. It occurs in the lower part of the Pasierbiec Sandstone Fm (Figs 3, 4) and extends to the east at the nearby village of Tokarnia (Cieszkowski *et al.*, 2015a). It displays features described by Flores (1959), who defined an olistostrome as a sub-aquatic sedimentary body, consisting of extraclasts represented by fragments (olistoliths), embedded in a finer-grained matrix (see later additions by other authors, e.g., Görler, 1968; Abbate *et al.*, 1970, 1981; Hoedemaeker, 1973; Richter, 1975; Naylor, 1981). This is a synorogenic olistostrome (Ricci Lucchi, 1986; Lucente and Pini, 2008), as are most olistostromes discussed in the literature. It also shows features of an endolistostrome that contains fragments of local sediments as well as those of an allolistostrome, containing exotic olistoliths derived from the basement rocks, uplifted and exposed at the margin of the basin (cf. e.g., Raymond, 1978). The first genetic type represents a chaotic complex, which consists of fragmented, disrupted sandstone layers and crumpled shales in between them (Fig. 5E). The sandstones within the olistostrome belong to the Pasierbiec and Osielec sandstone lithotypes. At the top of the olistostrome, a debrite occurs. It consists of a sandy-gravel matrix, with numerous shale clasts and pebbles, boulders and blocks of different exotic rocks and minerals, e.g., granitoids, micaceous schists, quartz, limestones, marls, and glauconitic sandstones. Among them are blocks of metabasite (Fig. 6E, G), 0.5–3.5 m in diameter. Moreover, ellipsoidal boulders of Early Palaeogene organogenic limestones, up to 0.7 m long, were found (Fig. 6F). They contain algae, bryozoans, small molluscs, corals, small and large foraminifera, mainly nummulites, as well as debris of echinoids (Fig. 6I).

According to Leszczyński and Malata (2002), the Siary Subzone in the Palaeogene was characterized by a significant deepening caused by subsidence, which resulted in the

formation of a trough, whereas in the Rača Subzone, a morphological elevation caused by the formation of an accretionary prism took place. This situation explains the limited occurrence of the Pasierbiec Sandstone Fm in the Siary Subunit as well as in the northernmost part of the Rača Subunit and its absence in the southern part of Rača Subunit. The clastic deposits of the Pasierbiec Sandstone Fm were transported from the north into the filling trough, but further transport of the material to the south was blocked by a morphological elevation in the Rača Subzone.

The composition of sandstones, conglomerates and debrites of the Pasierbiec Sandstone Fm gives some information about the structure of the source area of the ridge, which bounded the Magura Basin in the north. The core of ridge was built up of crystalline rocks of metabasites, granitoids, granitic gneisses, gneisses, phyllites and micaceous schists, as well as some volcanic rocks. The basement was covered by sedimentary rocks represented by some siliceous rocks, cherts, radiolarites and various limestones, including Mesozoic limestones with *Saccocoma* and Palaeogene organogenic limestones. The latest were deposited on a shelf, where the large foraminifera common in the Pasierbiec Sandstone Fm could live. The Pasierbiec Sandstone Fm contains also clasts and olistoliths of older rocks, known from the Magura Nappe succession. Their presence is connected with synsedimentary tectonic movements, which facilitated submarine erosion of the sediments on the bottom of the basin. These movements also triggered submarine slumps, which are evidenced in the lower part of the Pasierbiec Sandstone Fm. A somewhat similar scenario of a formation with submarine slumps and other olistostrome deposits was described by De Ruig and Hubbard (2006) from a deep-sea channel belt in the molasse foreland basin, located north of the Eastern Alps in Austria.

METABASITE PETROGRAPHY

The metabasite investigated is a medium-grained rock, dark green or green black in colour, showing a massive texture. The rock is in places strongly dynamically altered and shows irregular pale green or pale yellow green zones, up to 5 cm thick, which consist of macroscopically visible neogenic minerals, such as chlorite, epidote and calcite.

Microscopic studies of thin sections showed that cataclastic and mylonitic structures were formed in dynamically deformed parts of the metabasite. The phenomena of crushing mineral crystals, reduction of their size and abnormal optical properties of rock-forming minerals were observed. In undeformed parts of the rock, some relics of primary poikiloblastic structure occur, where plagioclase and amphibole are the main rock-forming minerals. Plagioclase is represented by subhedral albite, characterized by multiple twinning of albite and undulose extinction (Fig. 8C). The central parts of albite crystals are filled with small grains of the neogenic epidote and zoisite. In the specimens studied, traces of metamorphic deformation were observed. In the deformed parts of the metabasite blocks (Fig. 8D), albite crystals are crushed and strongly altered into aggregates of muscovite flakes. Amphiboles are represented by olive

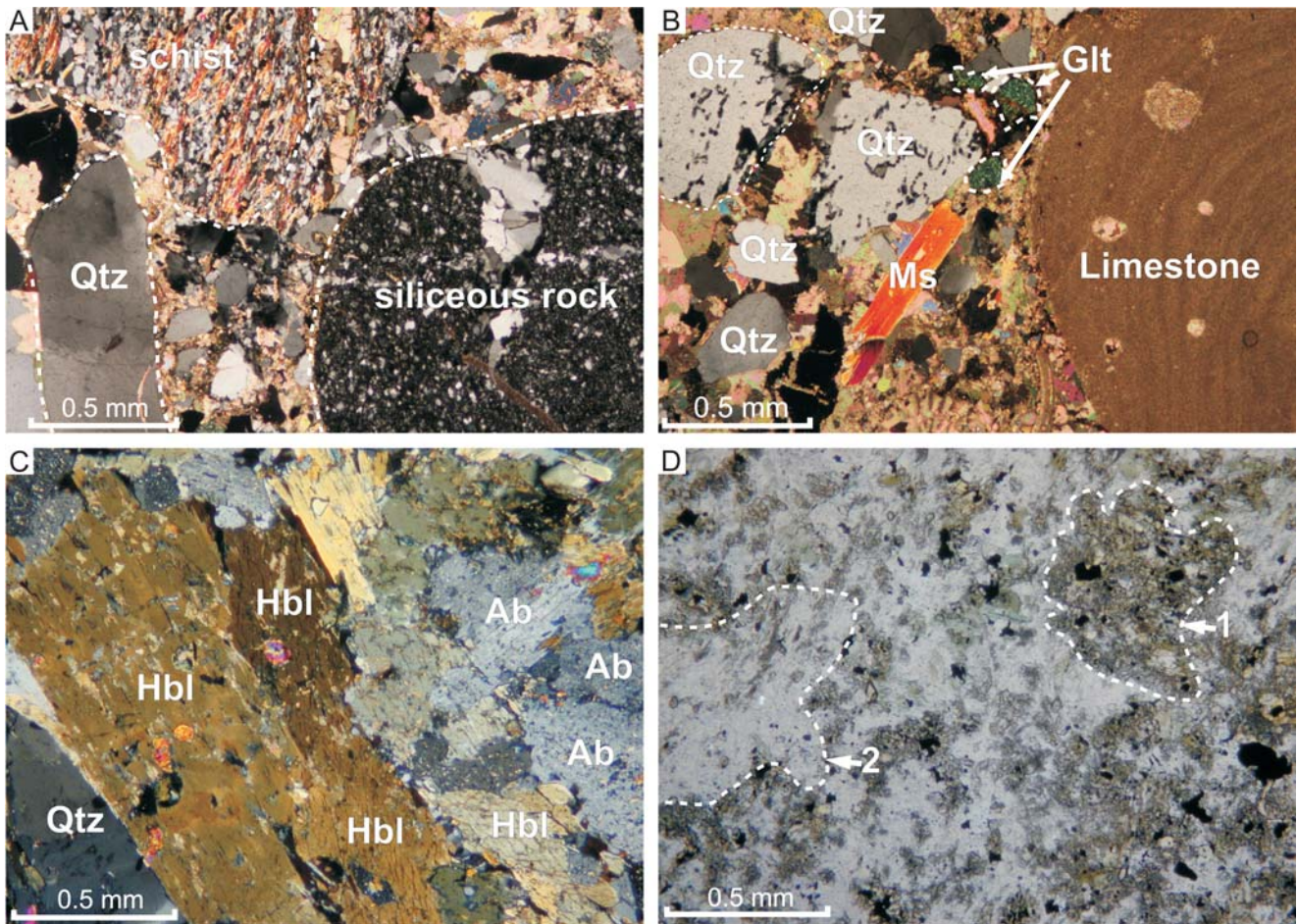


Fig. 8. Microscopic imagines of the studied rocks. **A.** Osielec Sandstone lithotype (sample no. Os-pas 12) – grain of quartz (Qtz) and lithoclasts of schist and siliceous rock. Cross-polarized light. **B.** Osielec Sandstone lithotype (sample no. Os-pas 4) – grains of quartz (Qtz) and glauconite (Glt), white mica flake (Ms) and limestone lithoclast. Cr ossed polars. **C.** Metabasite (sample no. OGK 1/1a/1) – crystals of amphibole (hornblende Hbl) and albite (Ab). Cross-polarized light. **D.** Metabasite (sample no. OGK 1/1b/1). Deformed zone consists of (1) pseudomorphosis after mafic minerals (amphiboles) filled by fine-grained aggregate of epidote, chlorite and opaque minerals and (2) neogenic albite with fine-grained sericite flakes and epidote/zoisite crystals. Plane-polarized light.

hornblende, which shows strong pleochroism from yellow green to olive green in colour. Hornblende tends to form elongated crystals, altered to different degrees, and partially replaced by aggregates of secondary epidote, sphene, chlorite and opaque minerals (Fig. 8D). Accessory minerals are represented by apatite, ilmenite and rare zircon. Petrologically, the metabasite studied can be determined as a cataclastic amphibolite. The blocks of metabasite are cut by calcite veinlets, containing pyrite and chalcopyrite. Preliminary investigations of its absolute age give a date of ca. 600 Ma (Anczkiewicz *et al.*, 2016), which means that these igneous rocks were formed in Neoproterozoic times during the Cadomian Orogeny. In general, the results of microscopic research of this rock correspond with the results obtained by Wieser (1952), though according to suggestions by Książkiewicz (1977b), the data for determination of the metabasite as an ophiolite are insufficient. The metabasite could have been created by metamorphism and cataclasis of a gabbro or gabbro-diorite (cf. Wieser, 1952), therefore sometimes it was described as “gabbro” (e.g., Cieszkowski *et al.*, 2010; Kysiak, 2010b; Anczkiewicz *et al.*, 2016).

TECTONICS

In the Osielec area, the Siary and the Rača subunits of the Magura Nappe occur (Figs 2, 4). In the southern and central part of the village, within the Rača Subunit, Książkiewicz (1966) distinguished the tectonic unit called the “Osielec Skiba”. He noticed significant differences between the geological structure of the northern and the southern limbs of this “skiba”. Detailed investigations of the authors presented in this paper show that in fact the “Osielec Skiba” consists of two distinctly different thrust sheets: the southern Bystra Thrust Sheet and the northern Osielec Thrust Sheet (Fig. 4). In the northern part of the Osielec Thrust Sheet, the Grzybówka Anticline is northwardly overthrown. Its core is built up of the Pasierbiec Sandstone Fm and limbs of the Beloveža Fm and variegated shales. The northern, tectonically reduced limb is thrust over the Wątkowa Sandstone Mb of the Siary Subunit. To the south of the thrust sheet, the irregularly formed Wronków Syncline is filled in general with the Beloveža Fm. Another local anticline built up of Pasierbiec Sandstone Fm occurs NW of the hamlet of

Głodkówka. In the Wronkówka Syncline, strata of the Beloveža Fm are locally disharmonically refolded. The Bystra Thrust Sheet is overthrust on to the Osielec Thrust Sheet from the south. In the frontal part of the Bystra Thrust Sheet, the Głodkówka Anticline appears. It is built up of the Ropianka and Łabowa Shale formations in the core and of the Beloveža Fm in the southern part. In the south-eastern part of the area, south of the Głodkówka Anticline, there exist three smaller, irregular folds of the Przykrzec Fold Group, with W-E-oriented synclines, composed of sandstones of the Magura Fm and anticlines made up of the Beloveža Fm. In the anticlines, the strata of the Beloveža Fm are disharmonically refolded (Fig. 4). Toward the west, these folds steeply decline. In the southwestern part of the study area, the regular Łysa Mount Syncline is located, with an axis oriented WNW-ESE. In its northern limb, sandstone beds of the Magura Fm are dipping to the south at angles of 45–65°. In the Osielec area, the fold structures and thrust sheets of the Magura Nappe are cut by a transverse system of strike-slip and oblique faults, oriented mainly N–S, NNW–SSE and NNE–SSW, and also close to NW–SE and NE–SW (Fig. 2). The majority of the faults are observable over a distance of less than 2 km. One of the longest is a fault located at Osielec Dolny, which influences the S–N course of the Skawa River and the lower reaches of Osielec Stream. Another distinct S–N-oriented fault is observable in the south-eastern part of Osielec village. This anticlockwise transcurrent fault displaces the fold axes of the Przykrzec Fold Group. Another SW–NE-oriented fault runs west of the mountain Grzybówka and it is traced over 2 km.

CONCLUSIONS

The area around Osielec is one of the most interesting areas in the Outer Carpathians, where the geology of the Magura Nappe is best exposed. The area provides the best insight into the lithostratigraphic and sedimentological development of the sedimentary succession of the Rača Sub-unit as well as into the tectonics of this region.

Of particular importance is the Pasierbiec Sandstone Fm, which consists of the Pasierbiec Sandstone and the Osielec Sandstone lithotypes. Both of these lithotypes and also alternate in the same formation, in accordance with the previous data of Książkiewicz (1966). Therefore, their separation as lithostratigraphic units is not recommended. The petrological composition of the Pasierbiec Sandstone Fm sandstones and conglomerates is very diverse and includes clasts and pebbles of different igneous, metamorphic and sedimentary rocks.

In the Pasierbiec Sandstone Fm, an olistostrome was observed. The rocks represent debris flow and submarine slump deposits, containing different clasts and olistoliths. Large blocks of metabasites, unique in the Outer Carpathians, were found. Preliminary investigations revealed their Cadomian age and traces of metamorphism, probably referable to the Variscan orogeny. The transport directions measured indicate that the coarse clastic material was derived from the north. Its source area was located on the Grybów (Fore-Magura) Ridge,

which separated the Magura Basin from the Dukla Basin during the Palaeogene.

Studies on the structure of the “Osielec Skiba” thrust sheet described by Książkiewicz (1966) showed that it consists of two tectonic elements: the Osielec Thrust Sheet and the Bystra Thrust Sheet. There are significant differences in the development of the sedimentary successions in these thrust sheets. For example, the southern extent of the Pasierbiec Sandstone Fm is limited to the Osielec Thrust Sheet and it does not exist in the Bystra Thrust Sheet (Figs 3, 4). This demonstrates the considerable development of the thrust of the Bystra Thrust Sheet on to the Osielec Thrust Sheet, considerably more than 1 km.

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