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STRATIGRAPHY AND GEOLOGICAL STRUCTURE OF THE MAGURA NAPPE IN THE SOUTH-WESTERN PART OF THE GORCE MOUNTAINS, OUTER CARPATHIANS, POLAND

Mateusz SZCZĘCH[1*] **& Anna WAŚKOWSKA**[2]

[1] *Jagiellonian University, Institute of Geological Sciences, Gronostajowa 3a, 30-387 Kraków, Poland; e-mail: mateusz.szczech@uj.edu.pl*
[2] *AGH University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, Mickiewicza 30, 30-059 Kraków, Poland; e-mail: waskowsk@agh.edu.pl*
** Corresponding Author*

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Abstract: The south-western part of the Gorce Mts (Outer Carpathians) is composed of flysch deposits of the Krynica and Bystrica subunits of the Magura Nappe. The Krynica Subunit includes the Late Cretaceous–Paleocene Ropianka Fm, the Early Eocene Beloveža Fm, the Early Eocene–Oligocene Magura Fm and the Oligocene–Early Miocene Malcov Fm, while the Bystrica Subunit includes the Middle Eocene–?Oligocene Magura Fm, represented mainly by the thick-bedded Magura Sandstone. Thin- and medium-bedded sandstone-shale turbidites predominate in the other formations. The lithostratigraphic units are dated on the basis of foraminifers. The studied deposits accumulated in the southern part of the Magura Basin. Their detrital material was derived from a ridge, bounding the basin in the south. In the study area, the Krynica Subunit overthrusts the Bystrica Subunit. The studied deposits are folded, thrust and cut by numerous faults. The Turbacz Thrust Sheet and the newly identified Kudłoń Thrust Sheet were distinguished in the Krynica Subunit. Faults of different lengths and throws are transverse or oblique. Some of them form complex dislocation zones with lengths of up to several km. In general, the high-resolution digital elevation model DEM contributed significantly to progress in the geological and geomorphological research.

Key words: Late Cretaceous–Early Miocene, stratigraphy, foraminiferal assemblages, tectonics, high-resolution DEM.

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INTRODUCTION

The Gorce Mts are a significant part of the Polish Outer Carpathians. They are composed of thick Late Cretaceous–Miocene flysch deposits of the Krynica and Bystrica subunits of the Magura Nappe. The sedimentary sequence of the Magura Nappe in the Gorce Mts consists of several lithostratigraphic formations. The general lithostratigraphic divisions, distinguished in the sedimentary succession of the Magura Nappe in the south-western part of the Gorce Mts, and concepts regarding the tectonics of the Magura Nappe were presented in an almost complete form by Watycha (e.g., Watycha, 1963, 1966a–d, 1975, 1976a, b; Burtan *et al.,* 1978a, b). Some supplements to the lithostratigraphic divisions were proposed by Cieszkowski (Cieszkowski, 1979a, b, 1992, 1995, 2006; Cieszkowski and Olszewska, 1986; Cieszkowski *et al*., 1998b; Uchman and Cieszkowski, 2008a, b; Cieszkowski and Struska, 2009). Geological studies in the south-western part of the Gorce Mts, carried out in the years 2015 to 2018 (Cieszkowski *et al*., 2017; Szczęch and Cieszkowski, 2017, 2021), presented new data on the tectonics and lithostratigraphy. Accordingly, there was need to supplement the geological information of the Gorce area, on the basis of the current observations.

The main goal of this paper is to develop a coherent interpretation of the geological structure, to define the lithostratigraphic units in combination with biostratigraphical and detailed tectonic data on the study area. In addition, the modern methodology of geological mapping was developed on the basis of the methods using the high-resolution digital elevation model (DEM; Cieszkowski *et al*., 2017; Szczęch and Cieszkowski, 2017, 2021), which was used then during construction of the detailed geological map of this area (Szczęch and Cieszkowski, 2021). This paper presents the comprehensive geology structure of the south-western part of the Gorce Mts. The geological research was carried out by M. Szczęch. Micropalaeontological investigations were carried out by A. Waśkowska.

GEOLOGICAL SETTING

The research area, i.e., the south-western part of the Gorce Mts (Fig. 1), is located in the Western Outer Carpathians (e.g., Książkiewicz, 1977; Ślączka *et al*., 2006) in an area, composed of the deposits of the Magura Nappe. The Magura Nappe is the largest tectonic unit in the Polish sector of the Outer Carpathians. In the south, it tectonically borders the Pieniny Klippen Belt, and towards the north, it thrusts over the Dukla Nappe and units of the Fore-Magura Group of nappes. All together, they are overthrust on the Silesian Nappe (e.g., Książkiewicz, 1977; Golonka *et al*., 2005, 2006; Ślączka *et al*., 2006). Facies differences and tectonic features allowed the subdivision of the Magura Nappe into a few tectonic-facies subunits. The facies features are the most important, while the tectonic criteria play a rather supporting role (e.g., Cieszkowski *et al*., 1985). According to the widely accepted proposal by Koszarski *et al.* (1974), from the south to the north, these are the Krynica, Bystrica, Rača and Siary subunits. In the study area, the Campanian–Early Miocene deposits of the Krynica Subunit and the Middle Eocene–?Early Oligocene deposits of the Bystrica Subunit crop out.

PREVIOUS RESEARCH

Geological research was initiated in the southern part of the Gorce Mts and the adjacent areas by Uhlig (1888, 1890) and Szajnocha (1895, 1898) and was continued by Nowak (1927), Bujalski (1929) and Świderski (1932, 1933). After World War II, the greatest merit in the geological studies of this area was provided by Watycha, whose investigations were used for the geological map of Rabka (Świderski, 1953a, b). Some geological problems of the south-western foothills of the Gorce Mts were presented by Halicki (1959, 1961). Independently, Watycha (1963) presented the geology of the Gorce Mts. Following this, with co-authors he constructed a few sheets of the geological map at 1:50 000 with explanations (Watycha, 1966a-d, 1975, 1976a, b, 1978; Burtan *et al.,* 1978a, b). In these elaborations, three zones of the Magura Nappe in the Gorce Mts were distinguished: the Periklippen Folds Zone, Gorce Zone, and the Peri-Window (Mszana Dolna Tectonic Window) Zone. Watycha (1963, 1975, 1976a; Watycha in Burtan *et al.,* 1978a, b) proposed also the most suitable lithostratigraphic division of the Krynica Subunit in the Gorce Mts and adjacent areas. The geology of the drainage basin of the Jamne and Jaszcze streams in Ochotnica Górna (central part of the Gorce Mts) was presented by Sikora and Żytko (1968). Several papers on the geology of the Gorce Mts and their surroundings were published by Cieszkowski and co-authors (Cieszkowski and Sikora, 1975, 1976; Cieszkowski *et al.,* 1978, 1987, 1998a, b, 2015; Cieszkowski, 1979a, b, 1985a, b, 1992, 1995, 2005, 2006; Cieszkowski and Olszewska, 1986; Cieszkowski and Oszczypko, 1986). The regional geological cross-section Kraków – Zakopane, containing the deep geological structure of the Carpathians (Sikora *at al.*, 1980; Golonka *et al*., 2005, 2018; Cieszkowski, 2006) and recognized in the deep boreholes Nowy Targ IG-1, 3,853 m, Obidowa IG-1, 4,500 m, and Chabówka, 5,101 m (Cieszkowski *et al.,* 1974; Cieszkowski and Sikora, 1976; Sikora *et al.,* 1980; Paul and Poprawa 1992; Cieszkowski, 2006), extends not far from the western boundary of the study area.

Two additions to the Gorce National Park for nature protection (Cieszkowski *et al.,* 1998a; Chodyń and Szczęch, 2015) are supplemented with two geological maps; their eastern parts are based mainly on the Mszana Górna (Burtan *et al.,* 1978a, b) and Nowy Targ (Watycha, 1975, 1976a) sheets.

STRATIGRAPHY

Sedimentary succession of the Krynica Subunit

In the Krynica Subunit, the Ropianka Fm (Campanian–Paleocene), the Beloveža Fm (Early Eocene), the Magura Fm (Early Eocene–Oligocene) and the Malcov Fm (Oligocene–Early Miocene) crop out (Figs 2–4). Their deposits are very thick and poorly differentiated. The Ropianka Fm (700 m thick), and the Beloveža Fm are only locally present at the surface. They are covered by a 2,500 m-thick succession of the Magura Fm (Fig. 4), which, in turn, is covered by the Malcov Fm (more than 800 m thick).

***Ropianka Formation* (*Campanian–Paleocene*)**

The Ropianka Fm was previously called the Inoceramian Beds (Watycha, 1963; Sikora and Żytko, 1968; Cieszkowski and Sikora, 1975, 1976; Cieszkowski, 1985a), the Ropianka Beds (i.e., Książkiewicz, 1974; Cieszkowski and Oszczypko, 1986), the Nowy Targ Beds (Watycha, 1976a; Burtan *et al.*, 1978b), or the Szczawnica Fm (Birkenmajer *et al.*, 1979; Birkenmajer and Oszczypko, 1989; Chrustek *et al.,* 2005). It is a series of a thin- and medium-bedded sandstone-shale turbidites (Fig. 5A, C, D), intercalated with packages of thick-bedded sandstones and conglomerates (Fig. 5B, E). Usually, the packages are a few dozen metres thick, rarely more, e.g., up to 120 m on the Obidowa Ridge. The sandstones predominate within the thin- or medium-bedded deposits. The sandstones are fine- or medium-grained, muscovitic, well-sorted, fractionally graded, hard and crumbling into sharp-edged cubes. They are steel-grey when fresh and brighter when weathered. The frequently observed convolute lamination in the sandstones is characteristic for this formation. The complete Bouma sequence occurs in the thicker layers (Tabcd, $Tabc_{conv}d$) and the lower intervals usually are missing from the thinner layers (Tbcd, $Tc_{conv}d$, Tcd). Quartz grains are the main component of the sandstones; feldspar, muscovite, occasionally biotite and glauconite also occur. The cement of the sandstones is carbonate or

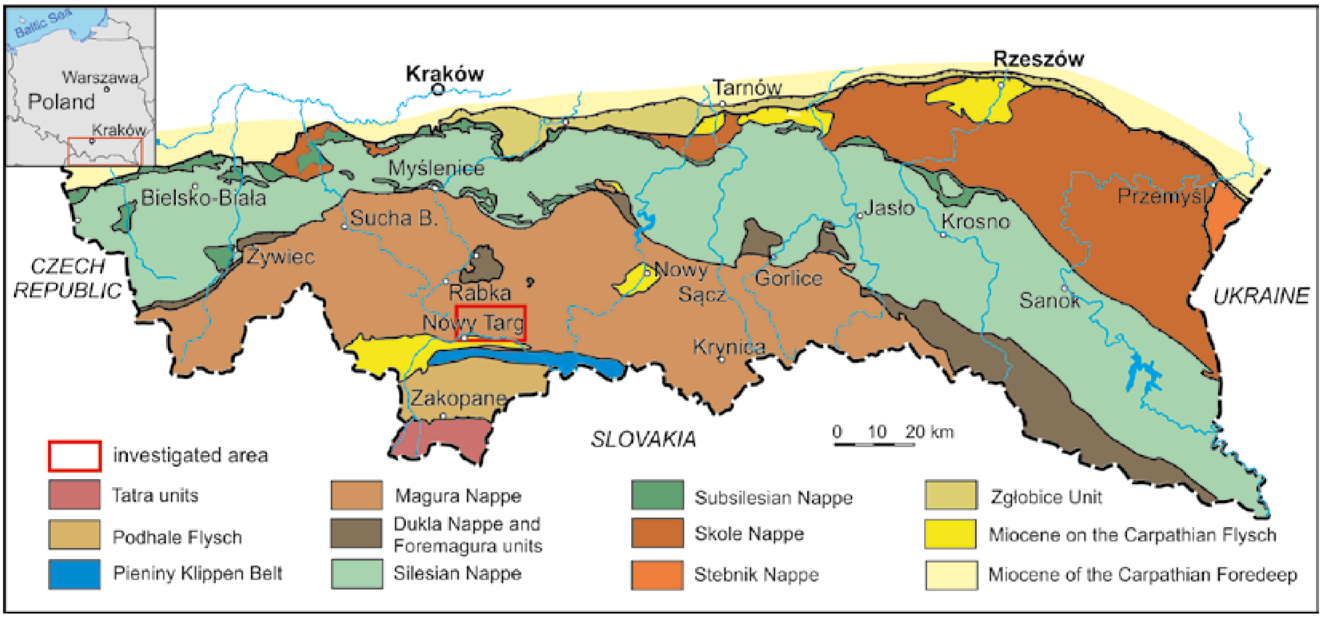


Fig. 1. Geological sketch map of the Polish sector of the Outer Carpathians (after Cieszkowski *et al*., 2017).

siliceous-carbonate, rarely clay-siliceous. Muscovite, often with admixtures of plant detritus, is concentrated on the surfaces of laminae.

The shales are grey, dark grey, greenish-grey, more or less marly mudstones and muddy claystones. In the upper part of the Ropianka Fm, yellow, marly shales also occur, in places with the trace fossil *Nereites*. Some single layers of hard, dark grey marls, 0.3–0.8 m thick, are also present.

The calcareous or calcareous-siliceous sandstones and massive conglomerates are grey or light grey, rarely grey-greenish in colour, thick bedded, commonly amalgamated, locally intercalated with thin- or medium-bedded shale-sandstone couplets of gravity flow origin. They form packages from a few to a dozen metres thick. The sandstones are coarse-grained and conglomeratic, with graded bedding. Parallel lamination and cross lamination occur occasionally in the upper part of the beds. Quartz predominates in the sandstones, and feldspar and muscovite occur as admixtures. The conglomerates occur in the basal parts of beds or form interbedded bands and only occasionally individual layers. Their grains are poorly sorted, up to 6 cm, mostly ca. 1 cm in diameter, and composed mainly of quartz, crumbs of gneisses, micaceous, chlorite and sericite schists, as well as clasts of quartzites, green claystones, limestones or dolomites. The palaeocurrent directions, measured in the thin-bedded flysch, show transportation from the E, and in the thick-bedded sandstones from the E and SE (Fig. 4).

Beloveža Formation (Early Eocene)

In the older literature, the Lower Eocene thin- and medium-bedded sandstone-shale deposits, located stratigraphically above the Ropianka (Inoceramian) Beds in the Krynica Subunit, were called the Hieroglyphic Beds (Bogacz and Węcławik, 1969; Oszczypko, 1973), the Beloveža Beds (Świdziński, 1972), or the Zarzecze Beds (Oszczypko 1975, 1979) and later the Zarzecze Fm (Birkenmajer and Oszczypko, 1989), and here are considered to be the Beloveža Fm. It is exposed in a small area, located in the NW part of the study area in Ponice, at the source of the Poniczanka Stream.

The Beloveža Formation consists of thin- and/or medium-bedded turbidites (Fig. 5). The sandstones are light grey or grey-bluish, fine-grained, calcareous, with parallel lamination and cross-lamination, rarely convolute lamination (Tbcd or Tbc$_{conv}$d and Tcd). Concentrations of muscovite with a plant detritus admixture occur on the surfaces of laminae, but muscovite is less frequent than in the Ropianka Fm. Numerous sole marks and trace fossils occur on the lower bedding surfaces. The sandstones are intercalated with shales in proportions of 1:1 and 1:2. The shales are bluish-grey, yellowish-grey and olive-green. Moreover, the layers of the thick-bedded sandstones and conglomerates occur in the thin- and medium-bedded flysch and are very similar to those of the Krynica Sandstone Mbr.

Krynica Sandstone Member (Early Eocene)

The Krynica Sandstone was described from the Magura Nappe in the vicinity of Krynica by Świdziński (1972) and formalized as the Krynica Sandstone Member within the Zarzecze Fm (Birkenmajer and Oszczypko (1989). This member stands out with regard to the thickness of the layers as well as the coarse-grained fraction and forms a sequence a few dozen metres thick within the thin- and medium-bedded flysch of the Beloveža Fm. It occurs in the source area of the Poniczanka Stream in Ponice Village. In the study area, this member thins out and finally disappears to the west, but thickens to the south, south-west and east, where it replaces almost completely the thin- and medium-bedded flysch of the Beloveža Fm. The lithology of the Krynica Sst Mbr is similar to that of the Piwniczna Sst Mbr of the overlying Magura Fm. Therefore, they were often considered to be the latter unit.

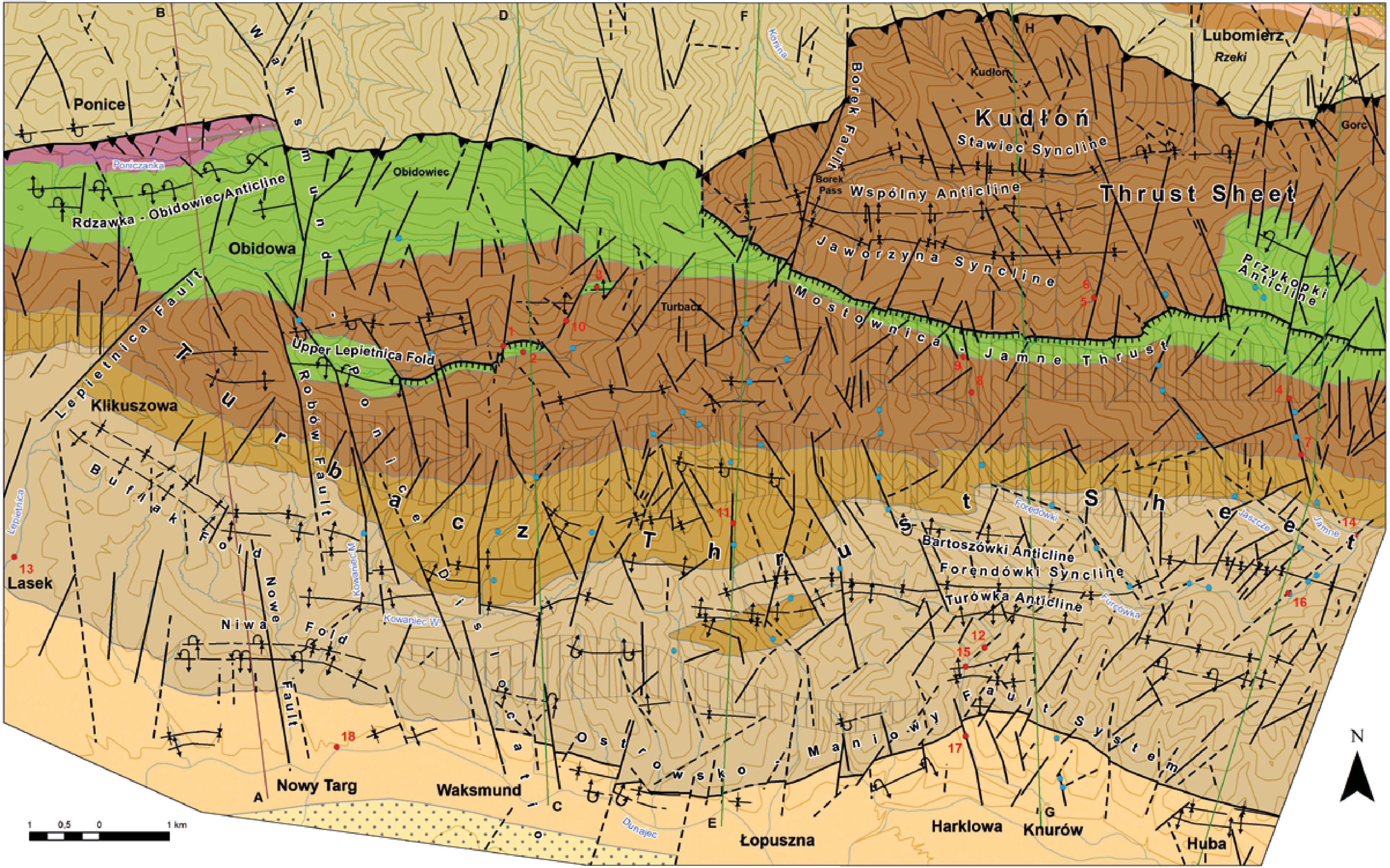


Fig. 2. Tectonic map of the south-western part of the Gorce Mts (based on Szczęch and Cieszkowski, 2021). Legend – see next page.

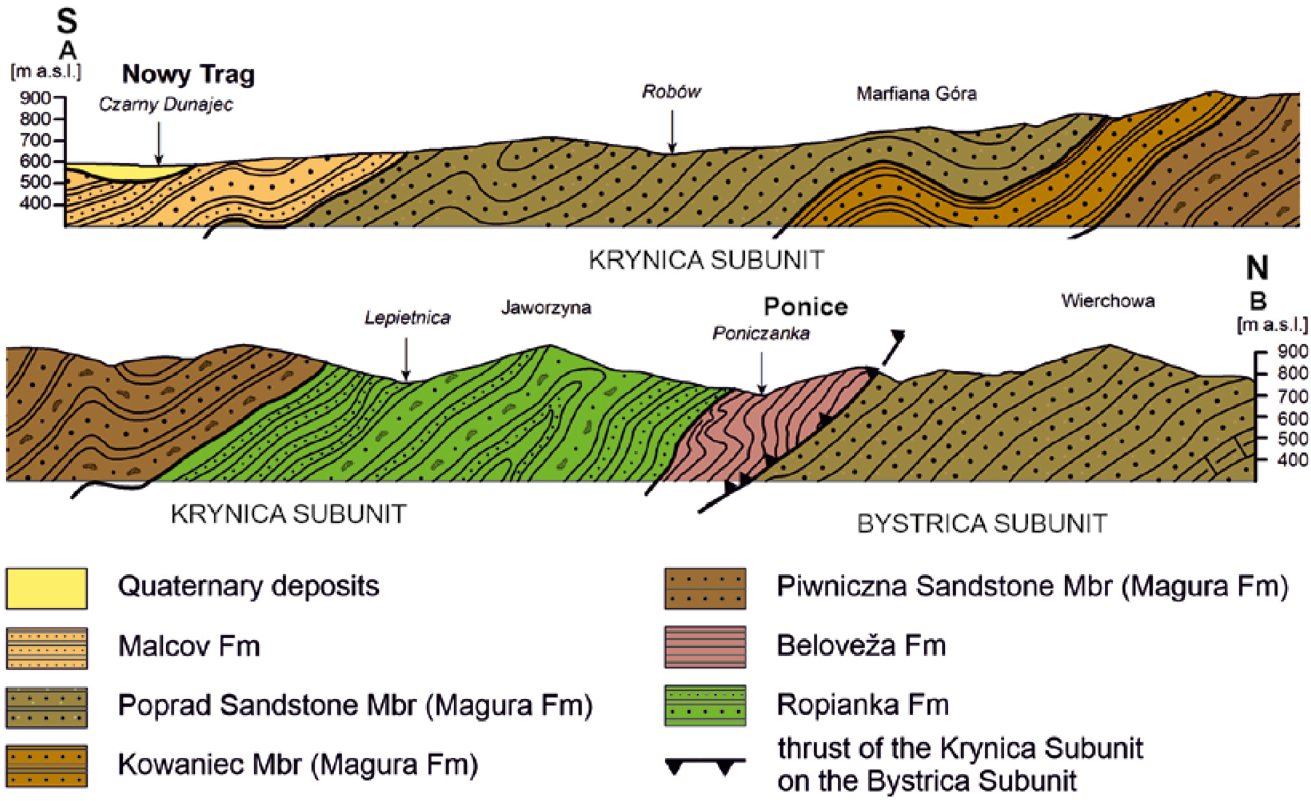
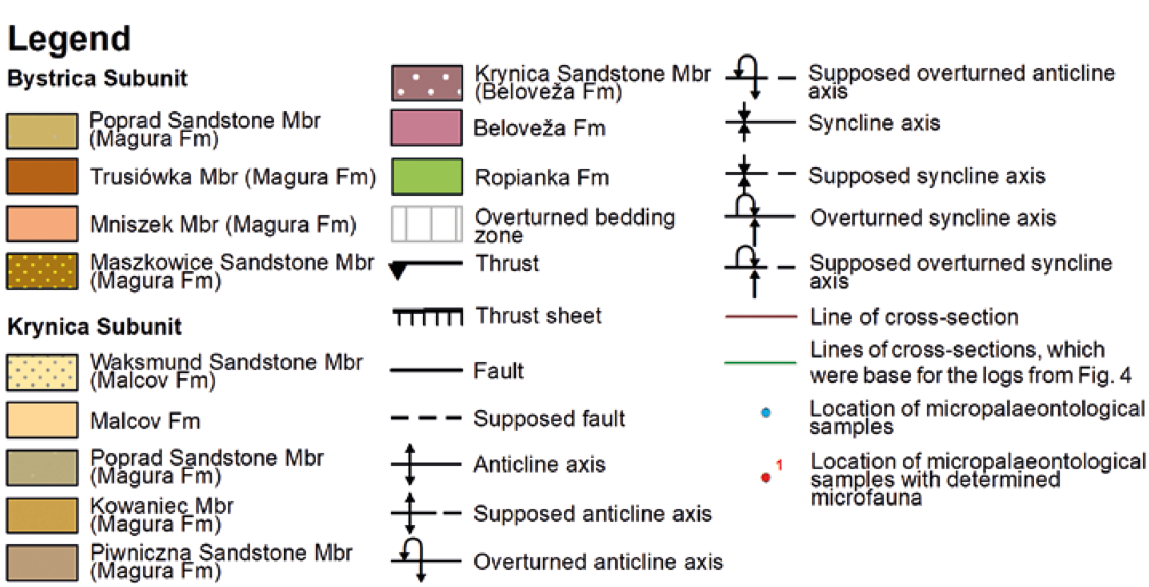


Fig. 3. Geological cross-section of the Magura Nappe in the study area (Szczęch and Cieszkowski 2021).

The Krynica Sst Mbr is developed as thick-bedded, coarse-grained sandstones, conglomeratic sandstones and fine conglomerates. The proportion of conglomerates is greater than in the other members of the Krynica Subunit. The sandstone beds are 0.5–1.5 m thick, but the amalgamated beds are up to 8 m thick or even more. The conglomerate grains are up to 1 cm, occasionally up to 3 cm or more, in diameters. As there are no clearer lithological and sedimentological differences between the Krynica Sst Mbr and the Piwniczna Sst Mbr, their detailed description is presented together in the chapter concerning the latter unit.

Magura Formation (*Early Eocene–Early Oligocene*)

The name "Magura Sandstones" was introduced by Paul (1868), who used it for the Eocene thick-bedded sandstones, making up the Oravska Magura mountain ridge in the northern part of the Orava region in Slovakia. These sandstones constitute a characteristic, easily distinguishable facies. By using the name Magura Sandstone in subsequent parts of this study, the authors understand it as being a designation of a facies, which is not confined to one lithostratigraphic unit.



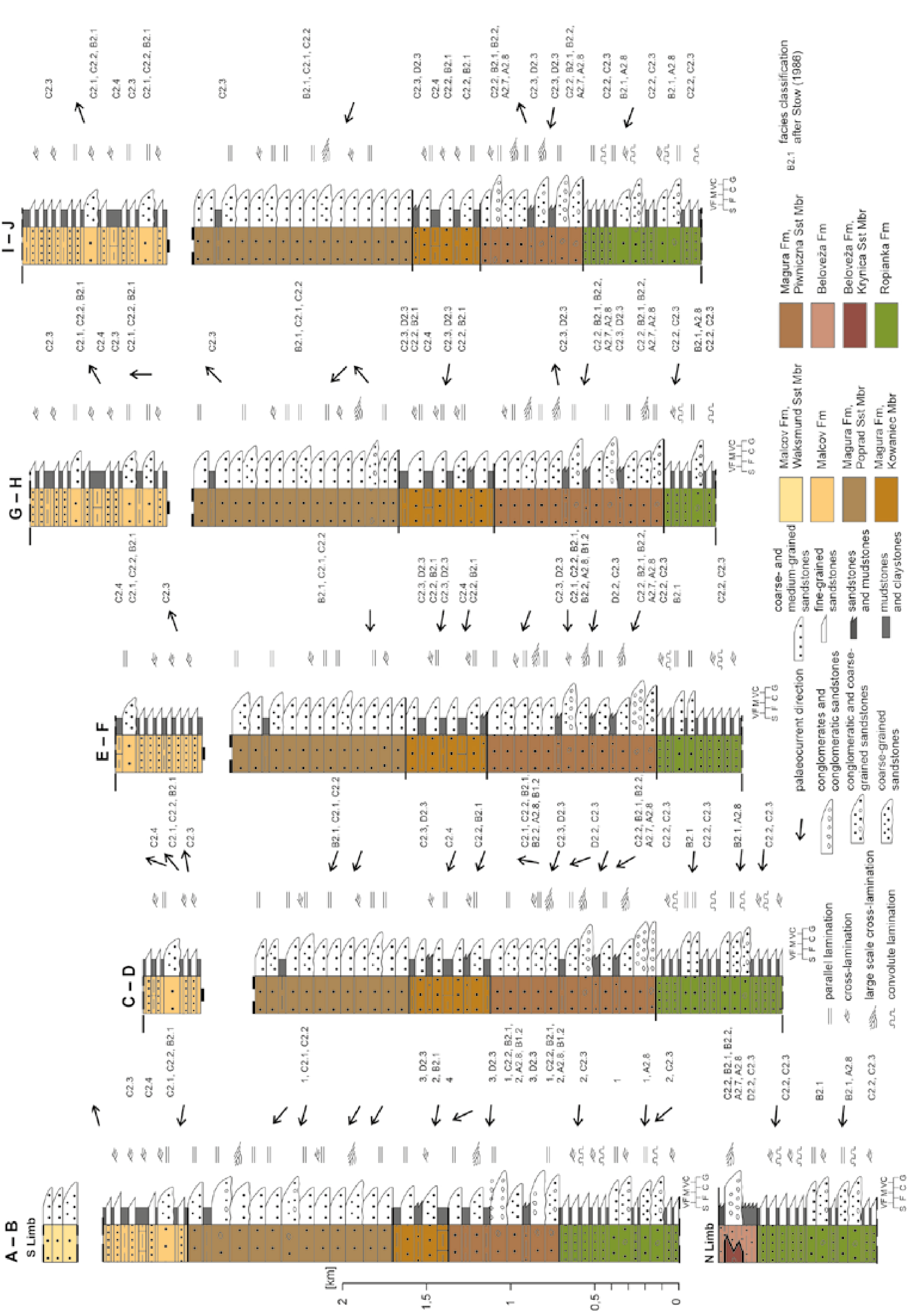


Fig. 4. Lithostratigraphic and sedimentological logs of sedimentary succession of the Krynica Subunit in the south-western part of the Gorce Mts (based on the cross-sections by Szczęch and Cieszkowski, 2021).

Fig. 5. Ropianka Fm. **A.** Thin- and medium-bedded sandstone-shale flysch (Obidowiec Stream valley). **B.** Thick-bedded sandstones (Obidowiec Ridge). **C.** Thin- and medium-bedded sandstone-shale flysch (Obidowiec Stream valley). **D.** Thin- and medium-bedded sandstone-shale deposits (Lepietnica valley). **E.** Thick-bedded sandstone in Obidowiec valley.

Książkiewicz (1953, 1958, 1966) distinguished two facies of the Magura Sandstone, a southern muscovite facies and a northern glauconite facies. The muscovite facies occurs in the Krynica, Bystrica and Rača subunits, while the glauconite facies is typical for the northern, marginal part of the Magura Nappe, called the Siary Subunit. The muscovite facies in the Krynica Subunit, especially in the Oravska Magura and adjacent areas, has a very characteristic development, so they could be treated as the Oravska Magura subfacies of the Magura Sandstone.

Beds of the Magura Sandstone are 0.5–2.0 m thick, but some amalgamated beds reach 10 m. The sandstones are calcareous, grey-bluish, when fresh or grey, yellowish-grey, when weathered, medium- and coarse-grained, and in some parts conglomeratic. They are usually massive (Ta), poorly sorted, rarely parallel laminated or cross laminated (Tab, Tabc). Quartz predominates, feldspar and muscovite also occur there, as well as lithoclasts of granitoids, gneisses, micaceous schists, phyllites, marbles, volcanic rocks, quartzites, lyddites, silicified siltstones, claystone shales, limestones and Triassic dolomites. The characteristic feature of the Oravska Magura subfacies is the occurrence of red and pink grains, represented by pink feldspar (orthoclase) and quartz, red and pink quartzitic sandstones (probably Werfenian) and some red or red-brownish volcanic rocks. This feature permits immediate recognition of the Magura Sandstone (Cieszkowski *et al.*, 1998b). The conglomeratic sandstones and conglomerates also have a similar qualitative composition as the sandstones. Owing to the fact that these rocks predominate in the Krynica Mbr, they are referred to as the Krynica Sandstone and/or the Krynica Conglomerate facies.

Birkenmajer and Oszczypko (1989) distinguished the Piwniczna Sst Mbr, the Mniszek Sh Mbr and the Poprad Sst Mbr within the Magura Fm in the Beskid Sądecki Mts. Watycha (1975, 1976a) and Cieszkowski (1979a) distinguished the Kowaniec Beds in the Gorce Mts, which could be located in the position of the Mniszek Sh Mbr. The deposits of the Magura Fm make up the main part of the study area and the highest peaks of the Gorce Mts, i.e., Turbacz (1310 m a.s.l.) and Kudłoń (1276 m a.s.l.).

Piwniczna Sandstone Member (*Early–Middle Eocene*)

The Piwniczna Sandstone Mbr in the Gorce Mts was originally called the Hieroglyphic Beds by Watycha (Watycha, 1963, 1966a–d), and next the Turbacz Beds (Watycha, 1975, 1976a; Watycha in Burtan *et al.*, 1978a, b). Cieszkowski and Sikora (1975) described these deposits as the Jaszcze Beds, while Birkenmajer and Oszczypko (1989) proposed for them another formal unit, the Piwniczna Sst Mbr. The Zábava Fm can be considered as the lateral equivalent of Piwniczna Sst Mb in Slovakia (Potfaj *et al.*, 1991; Teťák *et al.*, 2016a, b).

The Piwniczna Sst Mbr is represented by 1) thick- and very thick-bedded, often amalgamated sandstones of the Magura Sandstone facies (Fig. 6A–C) and also by 2) fine conglomerates, conglomeratic sandstones and sandstones of the Krynica Sandstone facies. The thick-bedded sandstones are intercalated with packages of thin- and medium-bedded shale-sandstone turbidites, similar to those in the Beloveža Fm (Fig. 6E, F). The Piwniczna Sst Mbr in the study area is exposed between Obidowa on the west and Ochotnica Górna on the east (Fig. 2).

The thick-bedded deposits of the Piwniczna Sst Mbr are represented mainly by medium- and coarse-grained sandstones, conglomeratic sandstones and fine conglomerates (Fig. 6D). The sandstones beds are 0.5–3.0 m thick, but occasionally amalgamated layers are much thicker. The sandstones are usually poorly sorted, but sporadically well-graded in the upper parts of the layers. The beds start with fine conglomerates or conglomeratic sandstones, which pass upwards into massive, medium- or coarse-grained, poorly sorted sandstone (Ta). In some beds, parallel lamination and cross lamination are present (Tabc; Fig. 6C). The sandstones of the Krynica Sst facies, conglomeratic sandstones and fine conglomerates usually occur in the lower part of the Piwniczna Mbr, i.e., in the Kiczora area, on the northern slope of the Jaworzyna Kamienicka Ridge and in the source part of the Lepietnica Stream, in the Turbacz area. Their contribution decreases upward within the section. The grains in the conglomerate vary around 1 cm, but larger grains up to 3–6 cm frequently occur. In the Piwniczna Sst Mbr, clay-carbonate, carbonate or carbonate-siliceous cement are present. This gives rise to their differential resistance to weathering. Trace fossils and sole marks rarely occur on the lower surfaces of the thick-bedded sandstones. The layers are separated with amalgamation surfaces, or soft, noncalcareous or occasionally marly mudstones.

In the thin- to medium-bedded flysch, a few centimetres thick, blueish-grey, fine- and medium-grained, parallel laminated and cross-laminated, rarely convoluted (Tbcd, $Tbc_{conv}d$) sandstones predominate. They are hard and disintegrate into sharp-edged and cuboid debris. They consist mainly of quartz and also of feldspars, muscovite, and carbonates, dispersed in the matrix. Trace fossils are abundant on the lower bedding surfaces. The sandstones are intercalated with marly, grey, grey-blue or yellowish shales and with noncalcareous shales, which predominate in the lowest part of this member. These types of deposits form packages that are a few centimetres to dozens of centimetres thick. However, they are several metres thick in the Łopuszna valley. The palaeocurrent measurements show that the clastic material was transported from the E in the thin-bedded sandstones and from the S and SSE and in the thick-bedded sandstone and conglomerates (Fig. 4).

Kowaniec Member (*Middle–Late Eocene*)

Originally, this division was called the Submagura Beds by Watycha (1963, 1966 a, b). It consists of thick-bedded sandstones and conglomerates with occasional intercalations of thick, shale-rich packages of thin-bedded shale-sandstone turbidites. The name used by Watycha was incompatible with the definition of the Submagura Beds, proposed by Książkiewicz (1966, 1974) for the Eocene deposits, underlying the Magura glauconitic sandstones in the most northerly zone of the Magura Nappe. The Submagura Beds there form a quite different lithosome, and subsequently they were called the Zembrzyce Shales (Książkiewicz, 1974). Then Watycha described this division in the Gorce Mts as the Kowaniec Beds (Watycha 1975, 1976a; Watycha in: Burtan *et al.,* 1978a, b), but he did not give a clear definition of this division. Cieszkowski (1979a, b) proposed its redefinition and named it the Kowaniec Mbr (Cieszkowski *et al.,* 1998b). He considered that it partially could replace the Mniszek Sh Mbr of the Magura Fm, created by Birkenmajer and Oszczypko (1989) and developed in the Beskid Sądecki as the thin-bedded shale-sandstone turbidite facies at the level of the variegated shales. The Račová Mbr can be

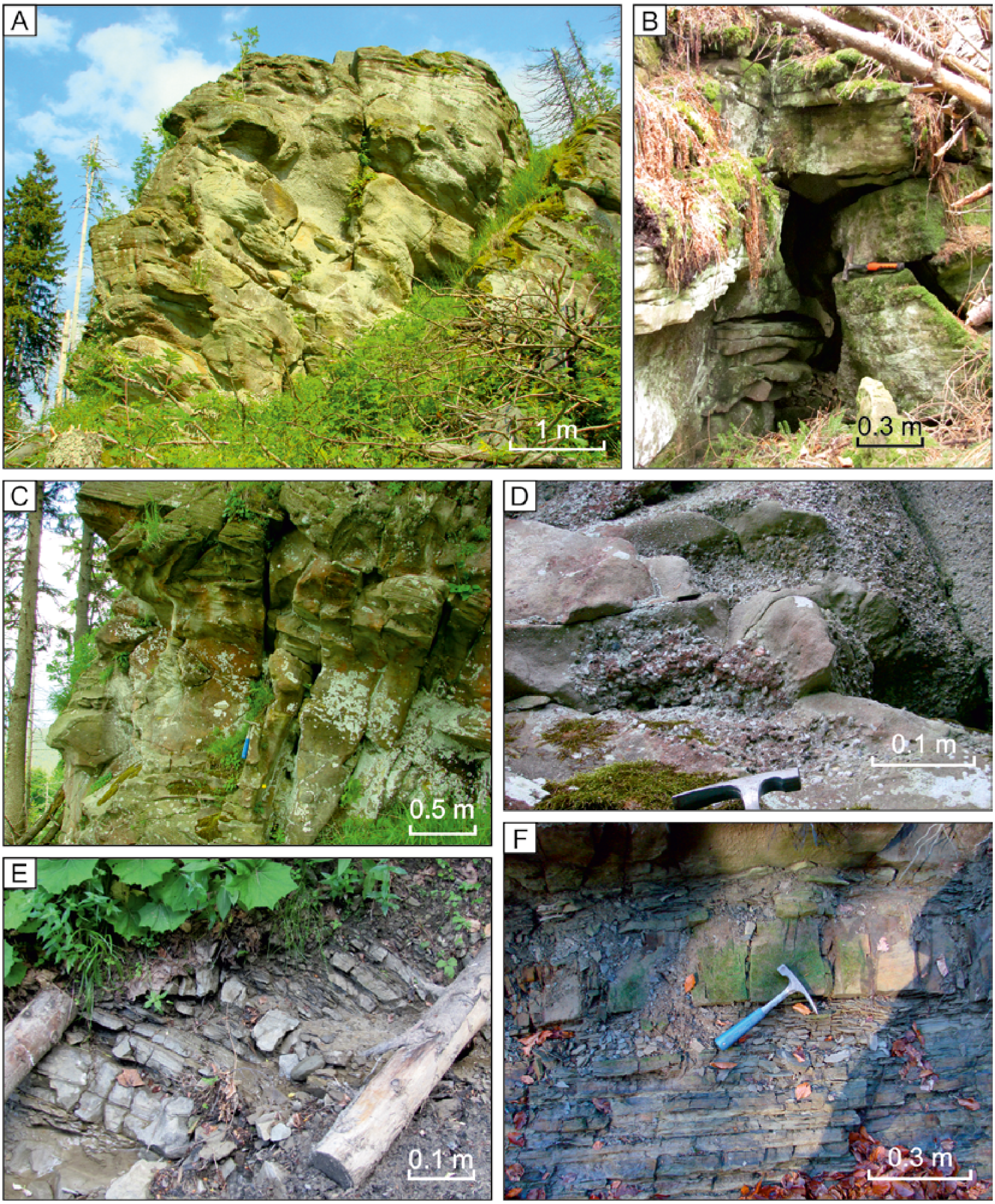


Fig. 6. Piwniczna Sst Mbr. **A.** Rock tower made up of the thick-bedded sandstones (the northern slope of Kudłoń Mt.). **B.** Rock cavity in the thick-bedded sandstones (at Stawieniec Stream, below blue tourist path from Rzeki to Borek Pass). **C.** Amalgamated thick-bedded sandstones (Białe Skały, Kudłoń Ridge). **D**. Flame structure in conglomerates (Białe Skały, Kudłoń Ridge). **E, F.** Thin- and medium-bedded sandstone-shale deposits (Kamienicki Stream valley).

Fig. 7. Kowaniec Mbr. **A.** Thick-bedded sandstone (in the right bank of Łopuszna Stream valley). **B.** Thick-bedded sandstones with intercalations of thin- and medium-bedded sandstone-shale flysch, Hieroglyphic Beds type, characteristic for the Kowaniec Mbr (Ochotnica Górna, Furcówka Stream). **C.** Thick-bedded sandstones with parallel lamination. **D.** Thin- and medium-bedded sandstone-shale flysch with domination of sandstones (Łopuszna Stream valley). **E.** Thick layer of the massive, green shales (Łopuszna Stream valley).

considered as the lateral equivalent of the Kowaniec Mbr in Slovakia (Potfaj *et al*., 1991; Teťák *et al*., 2016a, b).

The Kowaniec Mbr is composed in 70–80% of its volume of thick-bedded Magura Sandstone facies packages, but intercalations of other facies are diagnostic for this unit. They include layers of the disintegrating into coarsely pieces, less calcareous mudstone shales (Fig. 7E), thin-bedded shale-sandstone packages, similar to those in the Hieroglyphic Beds (Figs 7B, D, 8E), and single intercalations of thick-bedded, massive marly mudstones and marls, similar to the Łącko Marl in the Bystrica subunit (Fig. 8C, D). Palaeocurrent measurements show that the detritic material of the Kowaniec Mbr was derived from the E or SE.

Fig. 8. Kowaniec Mbr. **A.** Rock formation made up of the thick-bedded sandstone with a visible fault (Łopuszna, Wysznia Mt). **B.** Sole marks in the medium-bedded sandstones. **C.** Łącko Marl facies (Łopuszna valley). **D.** Layers of the grey Łącko Marl facies (Jamne Stream valley). **E.** Thin- and medium-bedded sandstone-shale flysch, Hieroglyphic Beds type, with thick sandstone layer (Ochotnica Dolna).

The thick-bedded sandstones, 0.5–2.0 m, occasionally up to 5.0 m thick, are mainly amalgamated, medium-grained, grey, weakly calcareous, and clayey, more susceptible to weathering (Figs 7A, C, 8A). In this member, conglomerates do not occur. Only thin, discontinuous layers of dispersed gravel-sized grains are present in the conglomeratic sandstone. The presence of shale and shale-sandstone intercalations facilitates erosion of the Kowaniec Mbr, manifested in the morphology of the research area, mainly in the formation of mountain passes.

The thin-bedded flysch contains thin- and medium-bedded sandstone-shale turbidites (Figs 7B, D, 8B). The sandstones are grey greenish, parallel laminated and cross-laminated, fine-grained, quarzitic, with a small amount of feldspar and muscovitic concentrations on the surfaces of laminae, non-calcareous, or rarely poorly calcareous. In some medium beds of sandstones, the complete range of Bouma intervals (Tabcd) is present, whereas intervals Tbcd or Tcd are more frequent in the thinner layers. The shales are greenish or grey-greenish, often noncalcareous and disintegrating into leaf- or plate-shaped pieces. Irregular thin intercalations of the variegated shales may occur (Watycha, 1966a, b). Usually, they disappear laterally over short distances.

The grey-greenish, thick-bedded, noncalcareous, rarely marly, occasionally silicified clayey mudstone shales break into large pieces (Fig. 7E). Their layers are mostly 0.5–8.0 m, but thick layers, a few metres in thickness, crop out in Łopuszna and in the Kowaniec Wielki and Kowaniec Mały stream valleys. The described shales represent thick-bedded turbidites.

A single bed, of sandstone-marly turbidite, 1.0–5.0 m thick, was observed in the thick-bedded sandstones in the Kowaniec Mbr (Fig. 8C, D). Such strata are more frequent in the Bystrica Fm and were previously called the Łącko Beds in the Polish sector of the Magura Nappe (cf. Oszczypko, 1991).

***Poprad Sandstone Member* (*Late Eocene–Oligocene*)**

The Poprad Sandstone Mbr is more than 1,000 m thick in the Gorce Mts (Fig. 4). It is composed almost entirely of thick-bedded Magura Sandstone facies. Intercalations of shales are very rare or absent. This member previously was described as the Magura Beds (Watycha 1963, 1966a–d; Watycha in Burtan *et al.,* 1978b; Alexandrowicz *et al.,* 1984; Cieszkowski and Oszczypko, 1986). Birkenmajer and Oszczypko (1989) formalized this division and called it the Poprad Sst Mbr. The best outcrops of the Poprad Sst Mbr in the research area are in a quarry in Klikuszowa Village (cf. Cieszkowski *et al.*, 1998b; Fig. 9A). The Racibor Fm can be considered as the lateral equivalent of the Poprad Sst Mbr in Slovakia (Potfaj *et al.*, 1991; Teťák *et al.*, 2016a, b).

The thick-bedded massive sandstones of the Poprad Sst Mbr are mainly medium- and coarse-grained, calcareous or clayey-calcareous, petrographically very similar to the sandstones of the older members of the Magura Fm. Their beds are mostly 0.5–2.5 m thick, but thicker, amalgamated beds also are present (Fig. 9A, B, D). Conglomeratic sandstones and conglomerates with a larger admixture of limestone clasts, up to 5.0 cm in size, occur in Huba Village and in the Forędówki Stream valley. Lenticular or irregular clasts of coal are present locally. Sole marks and trace-fossils – usually *Scolicia* (Fig. 9C) and *Zoophycos* – occur rarely on the lower bedding surfaces. Shale intercalations constitute ca 1–3% of the upper and lower part of the Poprad Sst Mbr, but they are almost completely missing in the middle part as, e.g., in the Klikuszowa Quarry (Fig. 9A; cf. Cieszkowski *et al.*, 1998b). In the uppermost part of the Poprad Sst Mbr, the proportion of thicker shale and thin- to medium-bedded shale-sandstone packages steeply rises (Fig. 9E).

The shale layers occurring as intercalations in the thick-bedded sandstones are olive-green, often gritty, noncalcareous, a few to several centimetres up to 50 cm thick, or even thicker in the uppermost part of the member, where soft, marly, light-grey shales often occur. Additionally, single, not thick layers of the Łącko Marl facies occur in the lower part of the Poprad Sst Mbr. In the Lasek and Nowy Targ areas, the transition of the Poprad Sst Mbr to the overlying Malcov Fm is observed. The palaeocurrent directions show that the detritic material in the lower part of the Poprad Sst Mbr was derived from the SE and E, while in the upper part from the S and SW.

***Malcov Formation* (*Oligocene–Early Miocene*)**

The youngest deposits of the Malcov Formation of the Magura Nappe at the southern foot of the Gorce Mts were considered as in the Magura Sandstone (Uhlig, 1898), the Cenomanian–Turonian Inoceramian Beds (Halicki, 1959) and the Beloveža Beds (Halicki, 1961). Watycha (1963, 1976a) assigned them to the periklippen facies of the Inoceramian Beds and called them the Nowy Targ Beds (Late Cretaceous–Paleocene). However, Cieszkowski *et al.* (1978), Cieszkowski and Olszewska (1986) and Cieszkowski (1992) showed that the Nowy Targ Beds and the neighbouring Kowaniec and Turbacz beds at the southern foot of the Gorce Mts (Watycha, 1976a) are younger than Late Eocene, because they lie above the Magura Fm in the normal lithostratigraphic position. Therefore, they were all together distinguished as the Malcov Beds (Cieszkowski, 1985b; Cieszkowski *et al.*, 1978, 1998b; Cieszkowski and Olszewska, 1986), which were formalized as the Malcov Formation (Birkenmajer and Oszczypko, 1989).

The most representative outcrop of the Malcov Fm in the study area is called "Samorody on the Dunajec" (Fig. 10A) and located on the left bank of the Dunajec River below the confluence of the Czarny Dunajec and Biały Dunajec rivers at Nowy Targ (e.g., Halicki, 1959, 1961; Watycha, 1963, 1976a; Cieszkowski, 1992; Cieszkowski and Szczęch, 2015). It is the reference section of the Malcov Fm in Poland (Birkenmajer and Oszczypko (1989). The Malcov Fm is composed mostly of medium- and thin-bedded sandstone-shale flysch (Fig. 10B, D, E) with local intercalations of shales, soft marls, or harder, massive marls similar to the Łącko Marl facies, several metres thick. Moreover, single beds or packages over a dozen metres thick of the thick-bedded Magura Sandstone facies are present in this formation (Fig. 10C).

Fig. 9. Poprad Sst Mbr. **A.** Magura sandstones in Klikuszowa Quarry (fot. M. Cieszkowski). **B.** Thick-bedded sandstones (Furcówka). **C.** Trace fossil *Scolicia* (Ochotnica Górna). **D.** Thick-bedded sandstones (Ochotnica Stream in Ochotnica Górna). **E.** Thick-bedded sandstones with intercalations of thin- and medium-bedded flysch deposits (Ochotnica).

Sandstones predominate over shales in the thin- and medium-bedded sandstone-shale deposits. They are grey-bluish, bright grey, when weathered, strongly calcareous, usually fine- and medium-grained, in some places with a yellowish-rusty coating. Dark coatings of manganese oxides on sandstones and occasionally manganese dendrites on the crack surfaces are characteristic of the Malcov Fm. The sandstones are well sorted, fractionated, with parallel laminations and cross-laminated. The Bouma intervals Tabcd, Tabcd, Tbcd occur and Tcd in the quite thin-bedded sandstones. Quartz predominates in the sandstones and feldspar and clasts of the carbonate rocks also occur, abundantly

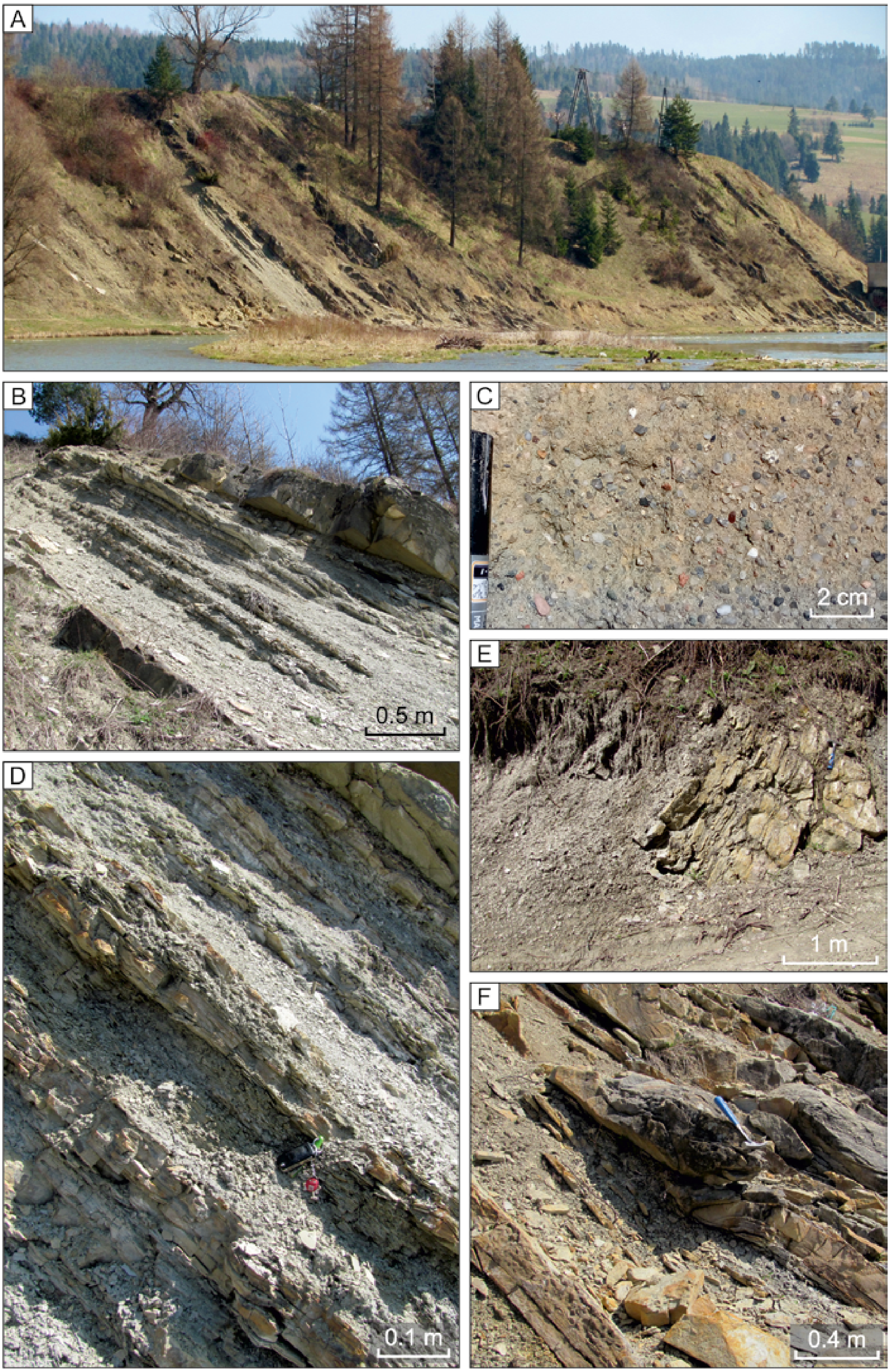


Fig. 10. Malcov Fm. **A.** „Samorody" nad Dunajcem – Malcov Fm outcrops (Nowy Targ). **B.** Thin- and medium-bedded sandstone-shale flysch (Samorody, Nowy Targ). **C.** Fine conglomerates of the Magura type with typical red and pink grains of the feldspar, quartz, quartzitic sandstones and volcanic rocks (Samorody, Nowy Targ). **D.** Thin-bedded sandstone-shale flysch (Samorody, Nowy Targ). **E.** Thick sandstone layer in packages of grey shales (Knurów). **F.** Submarine slumping with fragmented thick-bedded sandstone layers (Samorody, Nowy Targ).

in places. Muscovite with an admixture of fine plant detritus is concentrated on the lamination surfaces. Distinctly shaped sole marks and hypichnial trace fossils are common. The shale layers are up to several centimetres thick, marly, grey, bluish, yellowish or olive in colour. Intercalations of grey-yellowish and bluish marls, disintegrating into plate-shaped pieces occur occasionally. Small submarine slumps, which usually disrupt stratification are present in places, e.g., in the western part of the outcrop, Samorody on the Dunajec (Fig. 10F).

Thick beds or packages of thick (0.5–2.0 m) beds of the Magura Sandstone facies usually are amalgamated. Their petrographic composition is very similar to that of the underlying sandstones of the Magura Fm (cf. Figs 6D and 10C). Conglomeratic sandstones or/and fine conglomerates occur in the basal parts of some beds. Shale clasts, 5–25 cm in diameter, often occur. The measured palaeocurrents show that the material of the Malcov Fm was transported from the W or SSW (cf. Watycha, 1976a; Cieszkowski, 1992).

Waksmund Sandstone Member (*Miocene*)

The Waksmund Sandstone Member, 300–400 m thick, consists of thick-bedded Magura Sandstone facies, occasionally with interbeds of marly shales. It was described as the Waksmund Beds by Cieszkowski (1992, 1995) and recognized by him as deposits of the Lowest Miocene in the Krynica Subunit in the Nowy Targ area. These deposits also were recognized in the deep borehole Nowy Targ IG-1 and included in the Malcov Fm (Paul and Poprawa, 1992). Studies of the nannoplankton by Smagowicz (in: Paul and Poprawa, 1992) documented their Miocene age. Finally, Cieszkowski in Cieszkowski and Struska, (2009) defined them as the Waksmund Sst Mbr, the highest division of the Malcov Fm. The Waksmund Sst Mbr is poorly exposed and occurs mainly as weathered debris. Temporary outcrops of it were observed in trenches, excavated during the construction of the roadway along Wilcze Pole Street in Waksmund and John Paul II Street in Nowy Targ.

Sedimentary succession of the Bystrica Subunit

The Bystrica Subunit occurs only in the northernmost part of the research area between Ponice Village and Rzeki Hamlet of Lubomierz Village. It is represented there by the thick-bedded sandstones of the Poprad Sst Mbr, which are the youngest deposits of the Magura Fm.

Magura Formation (Middle Eocene–?Oligocene)

The Magura Formation in the Bystrica Subunit in the Gorce Range consists of few members (Oszczypko, 1991; Szczęch *et al.*, 2016). Its lithostratigraphic profile begins with the Maszkowice Sst Mbr, composed of thick-bedded sandstones of the Magura Sandstone facies (Fig. 11A, B). The next deposits are the thin-bedded sandstone-shale deposits of the Mniszek Sh Mbr (Fig. 11C). The Trusiówki Mbr occurs above it (Fig. 11D); it is represented by thick-bedded Magura Sandstone, intercalated with thin-bedded sandstone-shale packages. The Poprad Sst Mbr is the youngest division and is completely dominated by thick-bedded Magura Sandstone (Fig. 11E). The Poprad Sst Mbr in the Bystrica Subunit is similar to this member in the Krynica Subunit, but the grains of the thick-bedded sandstone are usually finer, conglomeratic sandstones are rarer and the fine conglomerates are exceptionally rare. The palaeocurrents show that the clastic material was delivered from the SE or ESE. Intercalations of shales or the Łącko Marl facies, 2–5 m thick, occur occasionally in this member. The shales are from a dozen centimetres to 2 m thick and occasionally more; they are usually dark grey, hard noncalcareous, and rich in dispersed muscovite. The Poprad Sst Mbr in the research area is about 1,000 m thick.

BIOSTRATIGRAPHY

Ca. 60 samples of mudstones, 0.5 kg each, were collected from most lithostratigraphic divisions for studies of the foraminifers (Fig. 2). The samples were subjected to a standard micropalaeontological procedure: disintegration in the Glaubert's salt solution, washing through sieves 0.63 mm and selection of fossils from the residuum obtained. Poorly preserved and usually not numerous tests of foraminifera, mainly agglutinated, were present (Figs 12, 13). Single radiolarians, Echinodermata spines, Porifera spicules and sporadically fish teeth were a supplementary component. However, only 18 samples contained microfossils in enough quantity for determination of the age (Fig. 2; Tab. 1). Apart from a few barren samples, only very low-diversity agglutinated foraminifera were found in the remaining samples, usually the tubular *Nothia* and *Bathysiphon*, and long-ranged *Glomospira*, *Recurvoides* and less frequently *Karrerulina* and *Paratrochamminoides*.

The samples Obidowa 345, 348, 384 and 369 were collected from the Ropianka Fm in the Obidowa area, along the upper part of the Lepietnica Stream. They all contain Late Cretaceous–Paleocene foraminifera, such as *Caudammina excelsa* (Dylążanka), *Rzehakina epigona* (Rzehak), *Dorothia trochoides* (d'Orbigny), *D. crassa* (Marsson), *Spiroplectammina dentata* (Alth), *S. spectabilis* (Grzybowski), and *Annectina grzybowskii* (Jurkiewicz). In the sample Obidowa 369, *Rzehakina inclusa* (Grzybowski) occurs among the Maastrichtian–Paleocene taxa. This species is known in the Outer Carpathians only from Upper Campanian–Maastrichtian deposits (e.g., Morgiel and Olszewska, 1981; Malata *et al.*, 1996; Cieszkowski *et al.*, 2007; Waśkowska, *et al.*, 2019) and its occurrence determines the interval biozone (Olszewska, 1997). The planktic *Globotruncana* cf. *ventricosa* (White) of Campanian–Maastrichtian age (BouDagher-Fadel, 2015 and references therein) is present in the sample Obidowa 345.

The foraminifers from about 40 samples, taken from the Magura Formation, are poorly and very badly preserved. Most of them are deformed and their identification was only possible at the genus level. Only samples Forędówki 284 and 291, Jaszcze 1 and 1a, and Jamne 4 from Ochotnica Górna yielded stratigraphically useful taxa. They contain large *Subbotina,* which is characteristic of the Late Paleocene and Eocene, and among others, *S. linaperta*

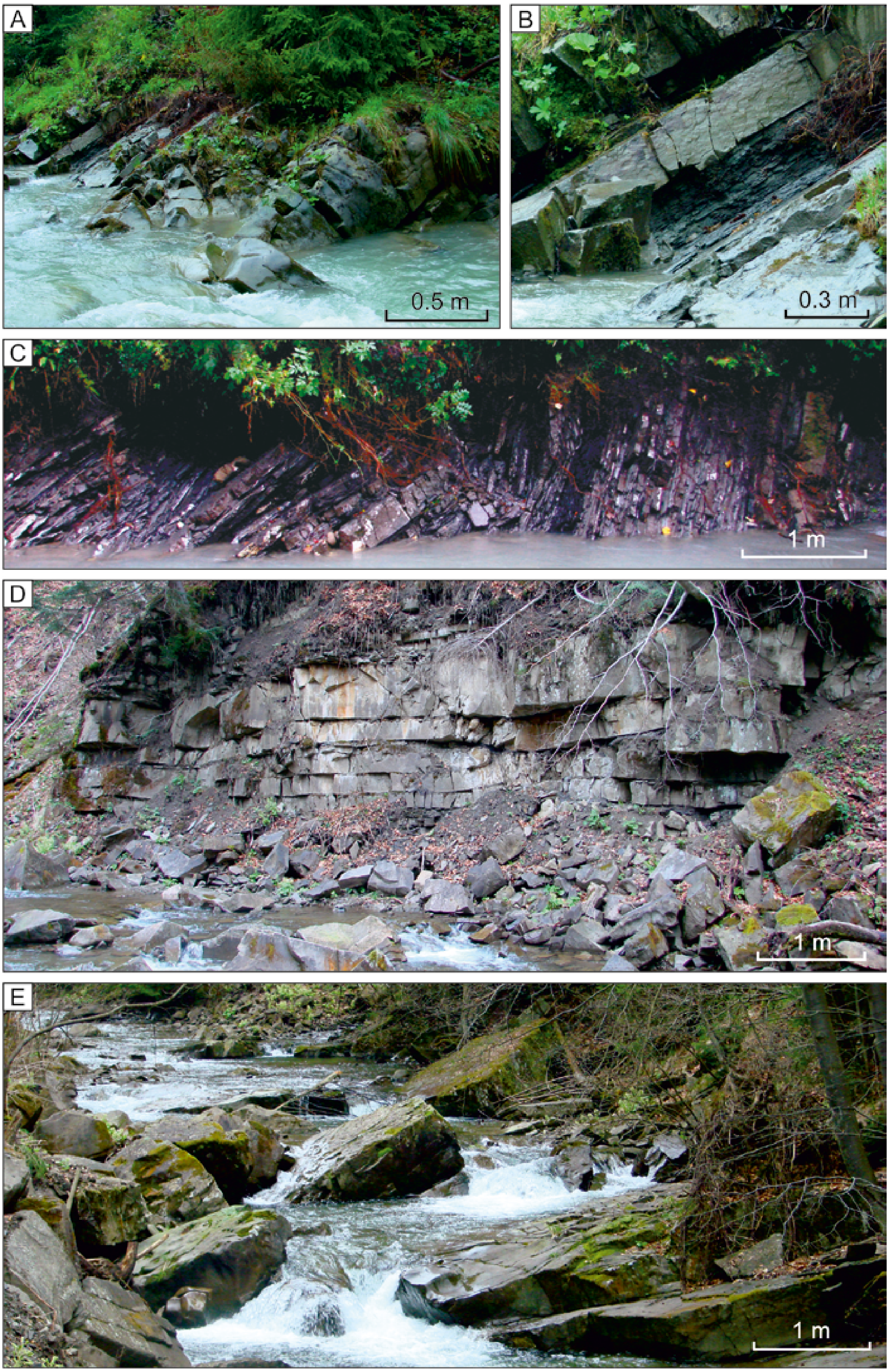


Fig. 11. Deposits of the Magura Fm in the Bystrica Subunit. **A.** Thick-bedded Magura sandstone type of the Maszkowice Sst Mbr (Rzeki, Lubomierz, Kamienicki Stream valley). **B.** Thick-bedded sandstones of the Maszkowice Sst Mbr with intercalations of bluish shales (Rzeki, Lubomierz). **C.** Thin- and medium-bedded sandstone-shale flysch of the Mniszek Mbr (Rzeki, Lubomierz). **D.** Thick-bedded sandstone of the Trusiówka Mbr (Kamienicki Stream valley, above Trusiówka meadow). **E.** Thick-bedded sandstone of the Poprad Sst Mbr (Kamienicki Stream valley).

Fig. 12. Selected specimens of foraminifera from the Magura Nappe deposits in the research area. **A.** *Bathysiphon* sp.; sample (s.) Klikuszowa Lasek. **B, C.** *Nothia excelsa* (Grzybowski); s. Jaszcze 1. **D.** *Nothia* sp.; s. Samorody. **E.** *Nothia* sp.; s. Ochotnica 189. **F.** *Psammosiphonella cylindrica* (Glaessner); s. Ochotnica 189. **G.** *Psammosiphonella cylindrica* (Glaessner); s. Foręḋówki 284. **H, I.** *Rhabdammina* sp.; s. Ochotnica 189. **J, K.** *Placentammina placenta* (Grzybowski); s. Ochotnica 189. **L.** *Ammodiscus tenuissimus* Grzybowski; s. Knurów 377. **M.** *Ammodiscus* sp.; s. Obidowa 345. **N, O.** *Ammodiscus peruvianus* Berry; s. Obidowa 369. **P, R.** *Glomospira charoides* (Jones et Parker); s. Knurów 289. **S.** *Glomospira gordialis* (Jones et Parker); s. Klikuszowa Lasek. **T, U.** *Glomospira gordialis* (Jones et Parker); s. Foręḋówki 284. **W.** *Glomospira glomerata* (Grzybowski); s. Foręḋówki 291. **X.** *Glomospira* sp.; s. Ochotnica 216. **Y.** *Glomospirella* sp.; s. Foręḋówki 291. **Z.** *Annectina* cf. *grzybowskii* (Jurkiewicz); s. Obidowa 369. Scale bar = 100 µm.

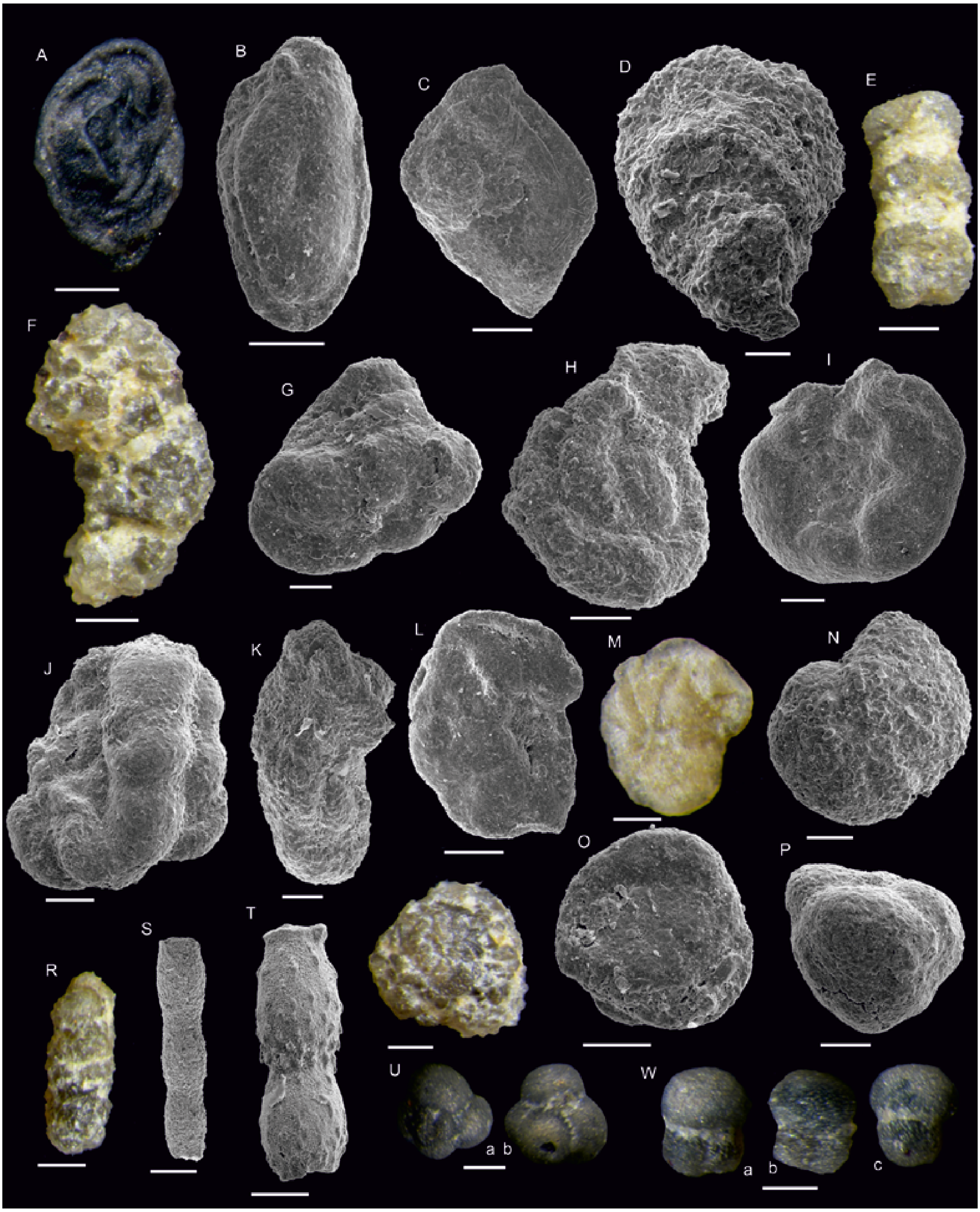


Fig. 13 Selected specimens of foraminifera from the Magura Nappe deposits in the research area. **A.** *Glomospira* sp. (irregularis-type); sample (s.) Knurów 377. **B.** *Rzehakina inclusa* (Grzybowski); s. Obidowa 369. **C.** *Rzehakina epigona* Rzehak; s. Obidowa 369. **D.** *Reophax* sp. (*pilulifer*-type); s. Ochotnica 216. **E.** *Subreophax scalaris* (Grzybowski); s. Ochotnica 189. **F.** *Reophax globosus* Sliter; s. Ochotnica 189. **G.** *Paratrochamminoides mitratus* (Grzybowski); s. Ochotnica 216. **H.** *Paratrochamminoides* sp. (*gorayskii*-type); s. Ochotnica 189. **I.** *Trochamminoides subcoronatus* (Grzybowksi); s. Ochotnica 189. **J.** *Paratrochamminoides mitratus* (Grzybowski); s. Knurów 377. **K.** *Paratrochamminoides vermetiformis* (Grzybowski); s. Ochotnica 189. **L, M.** *Haplophragmoides walteri* (Grzybowski); s. Ochotnica 189. **N.** *Recurvoides* sp. (*anormis*-type); s. Ochotnica 189. **M.** *Recurvoides* sp.; s. Klikuszowa Lasek. **O.** *Ammosphaeroidina pseudopauciloculata* (Mjatliuk); s. Forędówki 284. **P.** *Dorothia* sp.; s. Obidowa 369. **R.** *Karrerulia conversa* (Grzybowski); s. Ochotnica 189. **S.** *Nodosaria* sp.; s. Jaszcze 1. **T.** *Stillostomella* sp.; s. Klikuszowa Lasek. **U.** *Subbotina corpulenta* (Subbotina); s. Klikuszowa Lasek. **W.** *Subbotina linaperta* (Finlay); s. Klikuszowa Lasek. Scale bar = 100 µm.

Table 1

Taxonomic list of foraminifera from the lithostratigraphic divisions of the sedimentary succession of the Magura Nappe in the south-western part of the Gorce Mts.

Lithostratigraphic division	Ropianka Fm			Magura Fm						Piw. Mbr	Kow. Mbr	Poprad Mbr					Malcov Fm	
No. on the map (Fig. 2)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Sample No.	Obidowa 345	Obidowa 348	Obidowa 369	Jamne 4	Jaszcze 1	Jaszcze 1a	Ochotnica 216	Forendówki 284	Forendówki 291	Obidowa 364	Łopuszna 57	Knurów 389	Klikuszowa Lasek	Ochotnica 189	Knurów 385	Jamne 224	Knurów 377	Samorody
Acarininia sp.															x			
Ammodiscus cretaceous (Reuss)							x											
Ammodiscus cf. *latus* Grzybowski					x			x										
Ammodiscus perruvianus Berry			x								x			x			x	x
Ammodiscus restinensis Berry											x							
Ammodiscus tenuissimus Grzybowski	x		x									x					x	
Ammodiscus spp.	x				x			x		x	x							
Ammosphaeroidina pseudopauciloculata Mjatliuk	x	x	x					x									x	
Anomalinoides sp.																		x
Annectina grzybowskii (Jurkiewicz)			x															
Annectina sp.										x							x	x
Aschemocella grandis (Grzybowski)				x												x		
Bathysiphon sp.					x	x	x	x	x	x		x	x	x		x		x
Buzasina pacifica (Krasheninnikov)							x		x					x				
Cibicidoides praelopjanicus Myatlyuk											x							
Cibicides, Gyroidinoides and *Eponides* spp.		x	x			x								x				
Caudammina excelsa (Dylążanka)		x																
Cribrostomoides sp.										x	x							
Conglophragmium irregularis (White)														x				
Cystammina sp.			x														x	

Lithostratigraphic division	Ropianka Fm			Magura Fm						Piw. Mbr	Kow. Mbr	Poprad Mbr					Malcov Fm	
No. on the map (Fig. 2)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Sample No.	Obidowa 345	Obidowa 348	Obidowa 369	Jamne 4	Jaszcze 1	Jaszcze 1a	Ochotnica 216	Forendówki 284	Forendówki 291	Obidowa 364	Łopuszna 57	Knurów 389	Klikuszowa Lasek	Ochotnica 189	Knurów 385	Jamne 224	Knurów 377	Samorody
Dentoglobigerina baroemoenensis (LeRoy)																		x
Dorothia crassa (Marsson)			x															
Dorothia trochoides (Marsson)		x																
Dorothia sp.		x	x															
Eggerella cf. *propinqua* Brady																	x	
Globigerinatheka index (Finlay)											x							
Globigerina-type plankton																	x	
Globigerinella sp.																	x	
Globotruncana ventricosa White	x																	
Globotruncana-type plankton															x		x	
Globoturborotalia connecta (Jenkins)																	x	
Globoturborotalia sp.																	x	
Glomospira charoides (Jones et Parker)			x		x					x	x	x		x			x	x
Glomospira gordialis (Jones et Parker)			x					x				x	x					x
Glomospira glomerata (Grzybowski)									x			x						
Glomospira cf. *irregularis* (Grzybowski)			x				x										x	
Glomospira sp.			x			x	x	x		x							x	
Glomospirella sp.									x									
Haplophragmoides kirki Wickenden																	x	
Haplophragmoides cf. *horridus* (Grzybowski)														x				
Haplophragmoides walteri (Grzybowski)		x	x											x				
Haplophragmoides cf. *parvulus* Blaicher													x					

Lithostratigraphic division	Ropianka Fm			Magura Fm						Piw. Mbr	Kow. Mbr	Poprad Mbr					Malcov Fm	
No. on the map (Fig. 2)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Sample No.	Obidowa 345	Obidowa 348	Obidowa 369	Jamne 4	Jaszcze 1	Jaszcze 1a	Ochotnica 216	Forendówki 284	Forendówki 291	Obidowa 364	Łopuszna 57	Knurów 389	Klikuszowa Lasek	Ochotnica 189	Knurów 385	Jamne 224	Knurów 377	Samorody
Haplophragmoides cf. *porrectus* Maslakova										x								
Haplophragmoides sp.		x								x							x	
Hormosinelloides guttifera (Brady)														x				
Kalamopsis grzybowskii Dylążanka							x			x								
Karrerulina coniformis (Grzybowski)														x				
Karrerulina conversa (Grzybowski)		x	x									x		x				
Karrerulina spp.									x									
Lituotuba lituiformis (Brady)														x				
Neoponides lunata Brotzen											x							
Nodosaria/ Dentalina/ Stillostomella spp.		x			x	x					x		x	x				
Nothia excelsa (Grzybowski)	x	x	x	x	x	x	x				x			x	x			x
Nothia sp.			x				x	x	x				x	x				
Nuttallides truempyi (Nuttall)					x						x		x	x				x
Psammosphaera sp.										x								
Paratrochammino-ides div. sp.	x		x	x	x	x	x	x		x		x		x		x	x	x
Psammosiphonella cylindrica (Glaessner)			x				x				x			x			x	
Placentammina placenta (Grzybowski)		x	x	x				x		x				x		x	x	x
Praesphaerammina subgaleata Vasicek				x							x					x		
Pullenia spp.		x																
Rhabdammina sp.		x		x		x	x					x	x	x	x	x	x	x
Recurvoides div. sp.	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
Reophax duplex Grzybowski														x				
Reophax globosus Sliter														x				

Lithostratigraphic division	Ropianka Fm			Magura Fm						Piw. Mbr	Kow. Mbr	Poprad Mbr					Malcov Fm	
No. on the map (Fig. 2)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Sample No.	Obidowa 345	Obidowa 348	Obidowa 369	Jamne 4	Jaszcze 1	Jaszcze 1a	Ochotnica 216	Forendówki 284	Forendówki 291	Obidowa 364	Łopuszna 57	Knurów 389	Klikuszowa Lasek	Ochotnica 189	Knurów 385	Jamne 224	Knurów 377	Samorody
Reophax pilulifer Brady							x											
Rzehakina epigona (Rzehak)			x															
Rzehakina inclusa (Grzybowski)			x															
Saccammina grzybowskii (Schubert)				x			x			x				x		x		
Saccammina scrabosa Mjatliuk										x								
Saccammina sp.			x					x			x						x	
Spiroplectammina dentata (Alth)			x															
Spiroplectammina spectabilis (Grzybowski)			x															
Subbotina corpulenta (Subbotina)													x					
Subbotina linaperta (Finlay)								x			x			x	x			
Subbotina hagni (Gohrbandt)													x	x				
Subbotina-type plankton						x		x	x		x		x	x	x			
Subreophax scalaris (Grzybowski)			x	x			x	x	x	x				x		x		
Subreophax pseudo-scalaris (Grzybow-ski)							x							x				
Thalmanammina subturbinata (Grzy-bowski)			x									x		x				
Trochammina globi-geriniformis (Jones et Parker)			x						x					x			x	
Trochammina umiatensis Tappan																		
Trochammina sp.							x					x					x	
Trochamminoides subcoronatus (Brady)											x			x				x
Trochamminoides variolarius (Grzybowski)			x	x										x		x		

several faults. Watycha, in Burtan *et al.* (1978a, b), included the previous deposits comprising the Kudłoń Thrust Sheet to the Upper Cretaceous–Paleocene Ropianka Fm (Nowy Targ Beds *sensu* Watycha) that make up the northern part of the Turbacz Thrust Sheet. His maps did not separate the Kudłoń Thrust Sheet from the remaining part of the Turbacz Thrust Sheet. Later research showed that some deposits representing the Kudłoń Thrust Sheet are younger than the Ropianka Formation (Cieszkowski *et al*., 1998a). Research by the present authors showed that the deposits belong to the Lower Eocene Piwniczna Sst Mbr of the Magura Fm. As a result of these studies, the area of occurrence of the Ropianka Fm was reduced to only the northern front of the Turbacz Thrust Sheet (Fig. 2) in the area of the Forendówki and Jaszcze streams.

According to the studies of the present authors, the Turbacz Thrust Sheet occupies the main part of the Gorce Mts, with Turbacz (1,310 m a.s.l.) the highest peak of the massif, as well as their southern slopes. It descends in the south below the fresh-water Neogene and Quaternary deposits, filling the Orava-Nowy Targ Basin, just outside the boundaries of the research area. In the north-western part of the research area, it is directly related to the youngest deposits of the Bystrica Subunit, while to the east, from the Konina valley, it thrusts over the Kudłoń Thrust Sheet along the line of tectonic contact, which the authors called the Mostownica-Jamne Thrust (Fig. 2). Its strike follows more or less a latitudinal direction (W–E, WNW–ESE) and stretches along the source zones of the Furcówka, Forędówki, Jamne and Jaszcze streams, continuing probably eastwards, and further, just outside the study area. The Kudłoń Thrust Sheet thrust over the Eocene–?Oligocene deposits of the Magura Fm, which there make up the southern part of the Bystrica Subunit.

The flysch deposits in the tectonic units of the Magura Nappe described above were folded into a series of synclines and anticlines. In general, these are local fold structures with a relatively lower-rank within the Krynica Subunit. The fold structures are cut by strike-slip or oblique faults, mainly perpendicular and diagonal, causing displacements of the fold axes. The network of faults, dense in many places, combined with the limited flysch substrate outcrops, usually make it difficult to observe the course of local folds over a longer distance. The amplitudes of the folds in the Krynica Subunit are generally smaller than in the northern subunits. The folds are vergent to the north in the Kudłoń Thrust Sheet (Fig. 2). There are also zones with a southern vergence in the Turbacz Thrust Sheet, in addition to the northern fold vergence, that are manifested by the overthrow of a large part of the folds towards the south, often with the layers dipping to the N in the overturned position in the southern limbs. A southern vergence has been mentioned also in the area of direct contact of the Krynica Subunit with the Pieniny Klippen Belt (e.g., Sikora *et al*., 1980; Potfaj, 1989; Cieszkowski, 1992, 1995).

The fold structures that have been identified in the Krynica Subunit are mostly of local importance. In general, the axes of the folds present here strikes similar to the latitudinal E–W direction and they slightly turn, taking a WNW–ESE orientation towards the east. Directly, their E–W extension is close to the trend of the main fold structures in the central part of the Polish sector of the Outer Carpathians. A clearer change in the strikes of layers and extensions of the fold axes takes place only in the south-western part of the study area. Accordingly, the fold axes are oriented WNW–ESE and NW–SE (Fig. 2), which is typical for this part of the Outer Carpathians.

In the northern part of the Krynica Subunit, an anticlinorial structure is observed in the study area (Figs 2, 3). It is represented by the Rdzawka-Obidowiec Anticline, which overturns to N in the western part. First, this fold was recognized on the Kraków-Zakopane cross-section (Sikora *et al.,* 1980), west of the research area. The core of the fold is made up of deposits of the Ropianka Fm. Its northern limb is tectonically reduced and the deposits are partly preserved only in Ponice Village. To the east of the Waksmund-Ponice Dislocation Zone, the Beloveža Fm, as well as the part of the Ropianka Fm are tectonically reduced. The full reconstruction of this anticline on cross-section A–B (Fig. 3) shows that its amplitude is estimated as 1,500 m. Between Rdzawka and Konina, the anticline is overthrust on the thick-bedded sandstones of the Magura Fm, belonging to the Bystrica Subunit. To the east of the Borek Pass, its northern limb was reduced even further. Between Borek Pass and Jamne Hamlet in Ochotnica Górna, only a part of its southern limb, composed of the Ropianka Fm, is preserved. The deposits of the Ropianka Fm were thrust here along the Mostownica-Jamne Thrust line over the preserved part of the Kudłoń Thrust Sheet. The overturned layers dip to the S close to the Waksmund-Ponice Fault Zone, in the northern limb of the fold, and they are inclined at angles varying from 50–80^o. The angles of dip decrease and equal approximately 30^o close to the axis of the anticline; however, locally angles above 50^o are encountered. The angles are 20–50^o, and locally up to 70^o in the southern limb, which is composed partly of the Piwniczna Sandstone Mbr, but between the springs of Lepietnica and Jamne Hamlet, the southern limb is overturned. It is made up of the deposits of the Ropianka Fm and Piwniczna Sandstone Mbr and dips to the N in an inverted position at angles of 20–80^o, but usually 50–70^o. In the southern part of the research area, the Krynica subunit retains a synclinorial character. The Late Eocene, Oligocene and Early Miocene folded deposits of the Magura and Malcov formations predominate here.

Beside the above-described Rdzawka-Obidowiec Anticline, one of the most important structures is the Upper Lepietnica Fold, located in the upper section of the Lepietnica Stream valley. The core of the anticline in its central part is made up of the Ropianka Fm. In the western part, the anticline is overturned towards the north. The fold is cut by an inverse longitudinal fault in the eastern part that caused its strong reduction. Only part of its southern limb is preserved there. The periclinal closure is observed to the west of the Robów Fault, in the discussed fold, so the deposits of the Ropianka Fm disappear from the surface and the core is composed of the Piwniczna Sandstone Mbr. In the Upper Lepietnica Fold, the dip of the beds shows wide variation, from low angles to almost vertical.

Three fold structures in the Kudłoń Thrust Sheet, mainly composed of the Piwniczna Sandstone Mbr, were

(Finlay), which ranges from the Ypresian up to the end of the Priabonian (Olsson *et al*., 2006). However, in the opinion of other authors, its first occurrence is in the Late Paleocene (Toumarkine and Luterbacher, 1987; Olszewska *et al.*, 1996; BouDagher-Fadel, 2015). The occurrence of single specimens of *Praespherammina subgaleata* (Vašiček) and *Ammodiscus* cf. *latus* (Grzybowski) is characteristic for Middle–Late Eocene deposits (Geroch, 1960; Geroch *et al*., 1967; Jednorowska, 1968; Malata, 1981; Morgiel and Olszewska, 1981; Geroch and Nowak, 1984; Olszewska *et al*., 1996; Olszewska, 1997; Golonka and Waśkowska, 2011; Waśkowska and Kaminski, 2017).

From the Kowaniec Mbr, only sample Łopuszna 57 contains *Globigerinatheka index* (Finlay), which is a cosmopolitan Eocene planktonic taxon, ranging from the Middle Bartonian up to the Priabonian (Toumarkine and Luterbacher, 1987; Olszewska *et al.,* 1996; Li *et al*., 2003; Olsson *et al*., 2006). Moreover, the benthic species *Praespherammina subgaleata* (Vasicek) and *Cibicidoides praelopjanicus* Mjatliuk were determined. They occur in the Middle Eocene in the Outer Carpathian deposits.

In the Poprad Mbr, foraminifers are very rare and typically represented by *Nuttallides truempyi* (Nuttall) and deformed large *Subbotina*. The planktonic species, *Subbotina linaperta* (Finlay), *S. corpulenta* (Subbotina) and *Parasubbotina hagni* (Gohrbandt), which co-occur from the latest Ypresian up to the end of the Eocene (Toumarkine and Luterbacher, 1987; Olszewska *et al*., 1996; Olsson *et al*., 2006; BouDagher-Fadel, 2015) were recognized. The occurrence of *Praespherammina subgaleata* (Vasíček) in sample Jamne 224 and *Haplophragmmoides* cf. *parvulus* Blaicher in sample Klikuszowa Lasek indicates their Late Eocene age. In sample Knurów 389, the Late Cretaceous redeposited planktic foraminifera of *Globotruncana*-type were found along with large *Subbotina*.

In the Malcov Formation, only sample Knurów 17 revealed stratigraphically useful foraminifera. It contains *Globoturborotalia connecta* (Jenkins) and *Dentoglobigerina baroemoenensis* (LeRoy) of Late Oligocene–Miocene age (Cicha *et al*., 1998; Spezzaferri *et al*., 2018; Wade *et al*., 2018). They are accompanied by a few redeposited *Globotruncana*-type foraminifera of Late Cretaceous age.

The above biostratigraphic results presented here confirm the previous stratigraphic data for the deposits in the Magura Nappe of the Gorce Mts.

TECTONICS

The field study shed new light on the tectonic structure of the region. In the explanations for the Mszana Górna sheet of the Detailed Geological Map of Poland, 1: 50,000 (Burtan *et al.,* 1978b), it was mentioned that only two zones of the Magura Nappe occur in the study area: the Gorce Zone and the Peri-Tectonic Window Zone (adjacent to the Mszana Dolna Tectonic Window). In the Gorce Zone, Watycha, in Burtan *et al.* (1978a, b) recognized the Turbacz Thrust Sheet. There is a lack of any better information about the folds and faults that are present there. Only the fault, striking parallel to the Kowaniec Wielki Stream valley, was mentioned. On the tectonic sketch, the axes of a few synclines and anticlines were marked.

Following recently used nomenclature, proposed by Koszarski *et al.* (1974), the Magura Nappe in the research area is represented by the Krynica and Bystrica subunits. The Gorce Zone is a part of the Krynica Subunit and the Peri-Window Zone represents a part of the Bystrica Subunit. Each of them here retains tectonic individuality. The Krynica Subunit is thrust over the Bystrica Subunit. The northern margin of the thrust, generally latitudinal, is marked in the Gorce Mts with clear morphological expression, as a cuesta. It extends from the springs of the Poniczanka Stream in the west and further to the east, along the northern slopes of the Obidowiec Ridge, through the Borek Pass to the source area of the Konina Stream valley (Fig. 2). The thrust line turns to the SW–NE in the vicinity of the Borek Pass. This is caused by the sinistral strike-slip Borek Fault. Its eastern wall is pushed to the N, so the thrust trace is shifted toward the north about 1 km and forms a small curve along the northern slope of the Kudłoń Ridge.

Watycha (1963, 1975, 1976a) distinguished two smaller tectonic units within the Krynica Subunit: the northern Turbacz Thrust Sheet ("Turbacz Skiba") and the Peri-Klippen Folds Zone that overthrusts the Bystrica Subunit from the south. The Peri-Klippen Folds Zone, widespread in the southern foothills of the Gorce Mts, according to Watycha should have incorporated deposits of the Cretaceous, Paleocene and Early–Middle Eocene. The margin of the supposed thrust, called the Dział-Niwa-Wżar thrust line by Watycha (1963, 1975), was marked along the contact between the Late Eocene Magura Beds, belonging to the Turbacz Thrust Sheet and the Nowy Targ (Inoceramian) Beds, the oldest in the Peri-Klippen Folds Zone. The concept of the existence of the Peri-Klippen Folds Zone and its thrust over the Turbacz Thrust Sheet fell as a result of later research (Cieszkowski, 1985b, 1992, 1995; Cieszkowski and Olszewska, 1986; Cieszkowski *et al.,* 1998b). This research showed that the sequence of the deposits, supposed by Watycha to be Cretaceous–Middle Eocene in age, are in fact much younger, so they overlie the Magura Beds in the normal lithostratigraphic succession. The detailed tectonic investigations made by Struska (2008) also disproved Watycha's concept.

The authors of this article proved that the sediments of the Poprad Sandstone Mbr of the Magura Fm, dated as Late Eocene–Oligocene in age, normally pass up to the Oligocene–Early Miocene Malcov Fm deposits. This shows that the Watycha's idea of the so-called Dział-Niwa-Wżar thrust is out of date and the structure called the Peri-Klippen Folds Zone is not a separate thrust sheet but an integral part of the Turbacz Thrust Sheet. Notwithstanding, the normal stratigraphic contact between the Poprad Mbr and Malcov Fm is observed in Nowy Targ and its vicinity. Both divisions make contact tectonically along the normal fault further to the east. Its northern footwall is composed of the Poprad Mbr and the southern hanging wall, of the Malcov Fm (Fig. 2).

In the north-eastern part of the study area, the first author of the present paper distinguished an independent tectonic zone, Kudłoń Thrust Sheet. It is internally folded and cut by designated: the Stawieniec Syncline, the Wspólny Anticline, and the Jaworzyna Syncline (Fig. 2). The axes of these folds are oriented in a way that is similar to the latitudinal trend. Their axes become close to each other in the western part, where the Kudłoń Thrust Sheet gradually narrows and wedges out. Another irregular anticlinal structure, the Przykopki Anticline, occurs there, in the source area of the Jamne Stream. Its core consists of the Ropianka Fm and its northern limb of the Piwniczna Sst Mbr (Fig. 2). The Przykopki Anticline is delimited by transverse faults. Some smaller, irregular folds are observed within it. The Turbacz Thrust Sheet is overthrust northwards on the Kudłoń Thrust Sheet.

Some smaller, disharmonic folds, of characteristic short extent and with small amplitudes, appear in many places in the study area. Such small folds, formed in the Malcov Fm, deserve special attention in the southern, marginal part of the research area. These folds are upright or overturned with northern as well as southern vergence. Their formation undoubtedly was favoured by the greater susceptibility of the thin- and medium-bedded sandstone-shale turbidites of the Malcov Fm. Some small, usually disharmonic folds, observable on the scale of an exposure, also occur in the research area in many places (Fig. 14A). They most often formed in the sandstone-shale or shale packages, interbedding complexes of thick-bedded sandstones in the Piwniczna Sst Mbr and Kowaniec Mbr, as well as in the Ropianka Fm. Special phenomena in the study area are zones of beds, overturned to the south. They dip to the N in an inverted position, with hieroglyphs on the tops of beds. Local folds in these zones have a southern vergence. At least three belts of layers arranged in this way can be distinguished in the research area. The southern vergence in these zones is marked on the tectonic map (Fig. 2) and can also be seen on the geological cross-section (Fig. 3).

Numerous transverse or oblique, usually strike-slip or oblique-strike faults occur in the study area. Their lengths, throw and strike orientation are different. Some of them form complex dislocation zones that are long, up to several kilometres. These zones play a more important role in the fault tectonics of the south-western part of the Gorce Mts.

The Waksmund-Ponice Fault, distinguished by Książkiewicz (1977), was interpreted as joining further to the NNW with the Skawa Fault. This dextral strike-slip dislocation system cuts all the fold structures of the Krynica Subunit and continues further to the NNW beyond the research area through the Bystrica Subunit and partly the Rača Subunit. Further to the south of Waksmund, the strike of the fault zone extends and continues towards Trybsz (Watycha, 1975, 1976a). This dislocation has an impact on the shift of the axis of the eastern part of the Orava-Nowy Targ Basin between Waksmund and Nowa Biała. In Watycha's (1975, 1976a) interpretation, it causes a contortion of the Pieniny Klippen Belt between Nowa Biała and Trybsz.

There are several smaller but significant dislocation zones west of the Waksmund-Ponice Dislocation Zone. One of them continues towards the SSW, out of the western boundary of the study area. It includes the Lepietnica Fault, which according to Baumgart-Kotarba (1992) and Baumgart-Kotarba *et al*. (2004) crosses the Orava-Nowy Targ Basin west of Nowy Targ and significantly influences its tectonic structure (Struska, 2008). Baumgart-Kotarba considered the dextral-slip Lepietnica Fault as a part of the larger Orava Fault Zone (Baumgart-Kotarba *et al*., 2004). The strike of the Lepietnica Fault is oriented NE–SW. Its fault plane is located in the valley of the Lepietnica Stream in Klikuszowa and Obidowa villages. This fault is one of several causing a clear down-ward displacement of the geological structure of the Orava-Jordanów Foothills, located to the west (Książkiewicz, 1970; Szczęch, 2013).

The Ostrowsko-Maniowy Fault System extends to the east of the Ostrowsko meridian. The sandstones of the Poprad Sst Mbr of the Magura Fm do not maintain stratigraphic continuity with the deposits of the Malcov Fm along the faults of this zone, but they stay in tectonic contact. The almost isoclinal arrangement of the layers, dipping primarily to the south in the western part of the studied area, guarantees the normal stratigraphical transition of the Magura Fm into the Malcov Fm. It changes radically to the east because of influences of the Ostrowsko-Maniowy Fault System. The sandstones of the Poprad Sst Mbr, to the north of the Ostrowsko-Maniowy Fault Zone, dip to the S, but most often in an inverted position. Therefore, the deposits of the Malcov Fm in the southern hanging wall make contact tectonically further to the east with increasingly older elements of the Poprad Sst Mbr. To the south of the fault zone in question, the deposits of the Malcov Fm form a separate structure. It could be assumed that the anticlinal structure formed here was cut by longitudinal faults. The younger deposits, represented by the Malcov Fm, are preserved in the hanging wall to the south of the fault; the older deposits, representing the Magura Fm, are preserved to the north of it in the footwall. Ultimately, the reconstruction of the tectonic structures with preservation of their form before the formation of the Ostrowsko-Maniowy Fault Zone is not easy and requires additional research. It can be assumed that the fault system discussed is related to the formation of the eastern part of the Orava-Nowy Targ Basin in the Neogene. Its recent northern geological margin runs near the southern border of the research area. It is a structural transition to the Orava-Nowy Targ Basin. However, the small number of outcrops prevents a more accurate interpretation. One of the most important faults, the sinistral strike-slip Borek Fault, already was mentioned. The margin of the Krynica Thrust is significantly shifted northward by about 1 km in its eastern wall (Fig. 2).

Tectonic breccias, cataclasites, microbreccias, and fault gouge, are observed in the area. They resulted from brittle deformation in dislocation zones of variable width, including significant, relatively wide tectonic mélange zones (Fig. 14B, D–F), e.g., in the Lepietnica Stream valley, below the church in Klikuszowa, on the border of Klikuszowa and Lasek villages, and in the valley of the Łopuszna Stream, as well as in the valley of the Ochotnica Stream, on the border of Ochotnica Górna with Ochotnica Dolna. In addition, the flysch rocks, especially the sandstones, are cracked more strongly close to the faults (Fig. 14C) and the joint network is dense here. Calcite veins, filling the joints, commonly thicker (up to a decimetre) in the fault zones, are common in the study area.

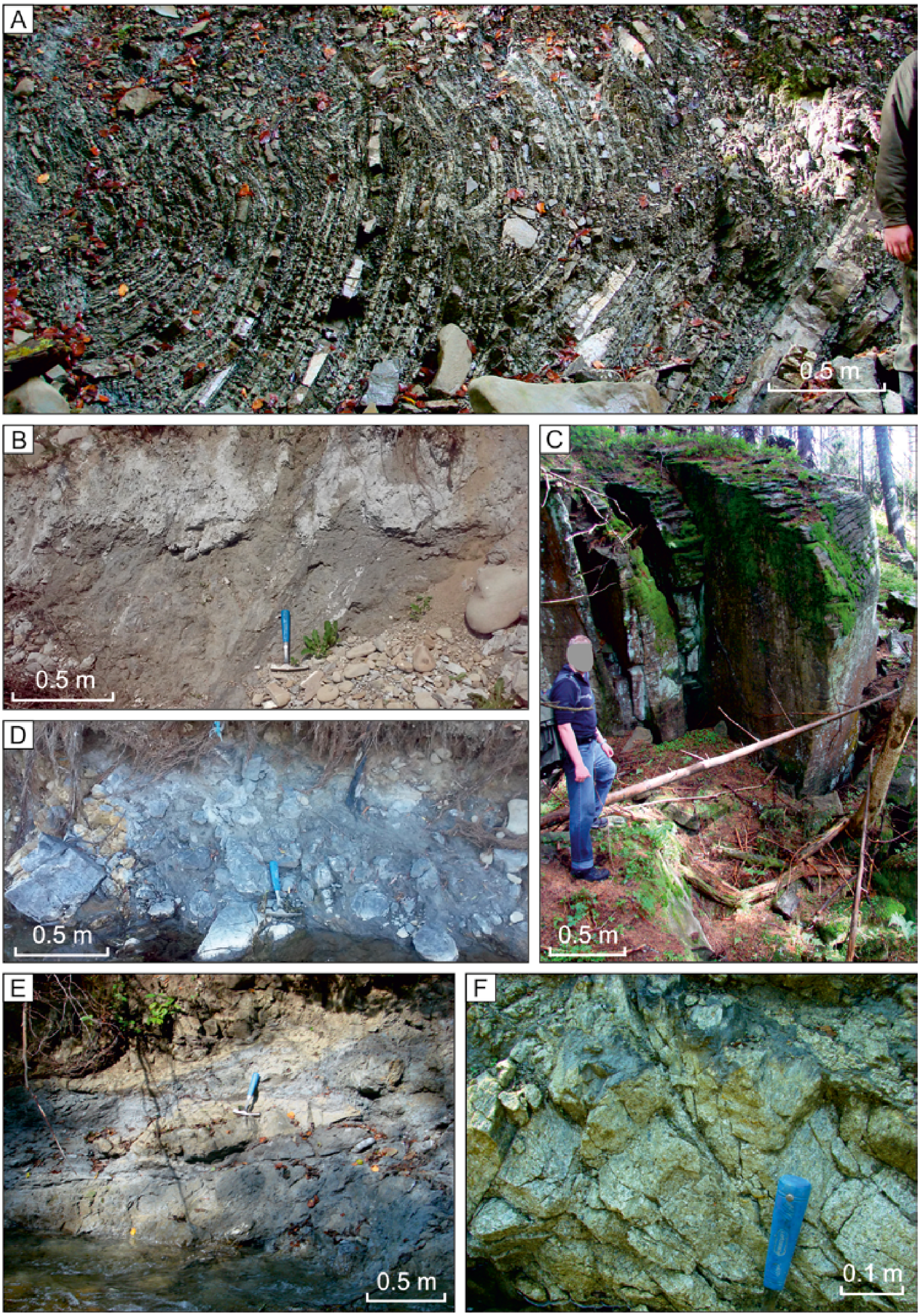


Fig. 14. Tectonic forms. **A.** Disharmonicaly folded packages of the Beloveža-like thin- and medium-bedded sandstone-shale flysch occurring between thick-bedded sandstones in the Piwniczna Sst Mbr (Łopuszna valley, above Żubrowisko). **B.** Fault zone with tectonic mélange (Łopuszna Stream valley). **C.** Blocks of thick-bedded sandstones in landslide apart along joint surfaces. **D.** Fault zone with tectonic mélange, with sandstone clasts in matrix (Ochotnica valley, located in the border area between Ochotnica Górna and Ochotnica Dolna; phot. M. Cieszkowski). **E.** Fault zone with tectonic mélange, with sandstone clasts in matrix (Łopuszna valley). **F.** Strongly crushed, partly mylonitized, coarse-grained sandstones of the Piwniczna Mbr (source part of Lepietnica Stream).

In the Cretaceous–Miocene sandstones of the Magura Nappe, the joint systems are clearly marked in the study area. In the Ropianka Fm, calcite veins are more common than in the younger deposits. The density of joints is greater here. They are more often covered with calcite coatings or the joints are completely filled with calcite. Random measurements of joint walls in sandstones of all members of the Magura Fm show that most of them are oriented WNW–ESE and NNE–SSW, but there are also joints with NE–SW and W–E orientations. Similar results have been obtained for the Magura Fm in Klikuszowa (Zuchiewicz in Cieszkowski *et al.,* 1998b). The SW–NE and WSW–ENE directions, in addition to the SSW–NNE ones, were often observed in the deposits of the Ropianka Fm in the region of the Obidowiec and Lepietnica stream valley, and rarely the WNW–ESE, as well as the W–E directions in the Obidowiec Stream valleys. The S–N direction predominates in the Malcov Fm in the Samorody on Dunajec geosite, while NNW–SSE directions are less common.

DISCUSSION

Comments on stratigraphy and lithology

The Campanian and Maastrichtian to Early Miocene sedimentary succession of the Krynica Subunit of the Magura Nappe is exposed at the surface in the study area. It is relatively monotonous, very thick and the boundaries between its lithostratigraphic divisions are not always clear. Between the Ropianka Fm and the Beloveža Fm there are no variegated shales of the Łabowa Shale Fm, which separate these formations clearly in the more northern subunits of the Magura Nappe. The separation of the lithostratigraphic members of the Magura Fm, dominated by the thick-bedded Magura Sandstone, is possible only thanks to the presence of other interbedded facies. Use of the digital elevation model (DEM) gave great accuracy in tracing the boundaries of the lithostratigraphic divisions, expressed in surface morphology in many places (Szczęch and Cieszkowski, 2021).

The petrographic composition of the thick-bedded sandstones and conglomerates in the Ropianka Fm is dominated by the erosion products of igneous and metamorphic rocks. The lithoclasts of sedimentary rocks are rather sporadic in distribution. The petrographic composition is more varied in the higher parts of the section, starting from the Krynica Sst Mbr within the Beloveža Fm. The lithoclasts of different sedimentary rocks occur there. This is also the case for the thick-bedded Magura Sandstone facies and conglomerates in the Magura Fm, as well as in the Malcov Fm, the composition of which is similar in the quality but may vary in the quantity of individual components throughout the entire profile (e.g., Cieszkowski *et al*., 1998b). The admixture of sedimentary rocks, including carbonates, increases noticeably, even becoming visible macroscopically in some parts of the Poprad Sst Mbr and then in the Malcov Fm. In terms of quantitative composition, an increase in the contribution of the lithoclasts of sedimentary rocks, including Werfenian quartzitic sandstones, Middle and Late Triassic dolomites and limestones, Paleogene carbonate rocks, is observed (Cieszkowski, oral information). Grains of pink quartz and lithoclasts of granitoids with orthoclase and/or plagioclases also occur, as well as red porphyry-like volcanic rocks. The spectrum of heavy minerals in the Magura and Malcov formations differs clearly from that recorded in the Ropianka Fm. The heavy mineral assemblages in the lithostratigraphic divisions younger than the Ropianka Fm are clearly dominated by garnet, as is seen even in the Magura Sandstone facies in the Miocene formation at Stare Bystre (Cieszkowski, 1995; Cieszkowski *et al*., 1998b; Cieszkowski and Struska, 2009). The presence of trace amounts of chromite spinel is also significant there.

Micropalaeontological dating of the Magura Nappe sedimentary succession in the study area and its immediate vicinity is still insufficient, mainly because of the absence of index taxa of foraminifers and calcareous nannoplankton, especially in the Magura Fm. However, significant progress was made in the southern part of the study area, where it appeared that the Malcov Fm is not older than the younger Late Eocene and could be an age equivalent to the Globigerina Marl (Cieszkowski *et al*., 1978; Cieszkowski and Olszewska, 1986). Later finds of large Oligocene foraminifera in the upper part of the Poprad Sst Mbr, previously considered to be Late Eocene, showed that the Malcov Fm is not older than Oligocene (Cieszkowski *et al*., 1998b). The discovery of marine Miocene deposits of the Krynica Subunit in the area S and SW of Nowy Targ, indicates that the Waksmund Mbr, the youngest division of the Malcov Fm, is Miocene in age (Cieszkowski, 1992). Its Early Miocene age was documented by Paul and Poprawa (1992). Calcareous nannoplankton (Oszczypko-Clowes *et al*., 2018) and the study of foraminifera from sample Knurów 17 point to the Early Miocene age of the Malcov Fm.

The Campanian–Maastrichtian–Paleocene age of the Ropianka Fm, determined on the basis of foraminiferal assemblages, is in agreement with the results obtained by Sikora and Żytko (1968) from the Jamne and Jaszcze stream sections and by Oszczypko *et al*. (1990) from the Krynica region. The Middle Eocene age of the Kowaniec Mbr is confirmed. The foraminifers from the Poprad Sst Mbr indicate only a Late Eocene age; however, an Oligocene age was indicated on the basis of calcareous nanoplankton by Wojciechowski (1999) and large foraminifera (see Cieszkowski *et al*., 1998b).

The deposits of the Szczawnica Fm (Birkenmajer and Oszczypko, 1989; Chrustek *et al*., 2005) are not sufficiently different from the Ropianka Fm in the Bystrica or Rača subunits and they do not constitute an independent lithosome, so the “Szczawnica Formation” term was abandoned. Furthermore, some deposits assigned to the Szczawnica Fm (Cretaceous–Paleocene; Birkenmajer and Oszczypko, 1989) east of the study area in the region of Krościenko and Szczawnica were considered to be Oligocene–Miocene in age (Oszczypko *et al.,* 2018). This weakens the usefulness of this division.

Similarly, the term “Zarzecze Formation” is abandoned because the Zarzecze Fm is not sufficiently distinguishable from the Beloveža Fm. The Beloveža Fm overlies the Eocene variegated shales of the Łabowa Fm and underlies the Bystrica Fm (Łącko Beds) or the Magura Fm in the typical sections of the Bystrica and Rača subunits (Oszczypko, 1991). In the Krynica Subunit, the Paleogene variegated shales do not occur, but deposits similar to the Beloveža Fm in terms of the lithological and sedimentological features (e.g., Oszczypko, 1991; Golonka and Waśkowska-Oliwa, 2007; Cieszkowski *et al.*, 2015) occur in the study area in more or less the same stratigraphic position. Therefore, the present authors restored in the Krynica Subunit the old name, "the Beloveža Beds", used by Świdziński (1972) in the formal "Beloveža Fm".

In the Beskid Sądecki Mts, the Mniszek Sh Mbr with a horizon of variegated shales was distinguished above the Piwniczna Sst Mbr and below the Poprad Sst Mbr. In the Gorce Mts, the Kowaniec Mbr, dominated by thick-bedded Magura Sandstone, occurs in this position.

Comments on tectonics

The tectonic basement of the Magura Nappe in the Gorce region is formed by the units of the Fore-Magura Group of Nappes. They are exposed at the surface north of the study area in the vicinity of the Mszana Dolna and Szczawa tectonic windows. More to the south, these units were identified in the boreholes, located close to the western boundary of the study area, in Obidowa IG-1 at a depth of about 2,700 m and in Chabówka-1 at a depth of about 1,900 m. The Grybów Nappe was drilled there just under the Magura Nappe and the Dukla Nappe was found below it (Cieszkowski, 2006; Cieszkowski in Golonka *et al*., 2005). The latter was referred to as the Obidowa-Słopnice Unit (Cieszkowski and Sikora, 1975, 1976; Sikora *et al*., 1980). The Obidowa-Słopnice Unit was found to be a western prolongation of the Dukla Nappe (Cieszkowski, 2003, 2006; Cieszkowski in Golonka e*t al*., 2005).

In this paper, a new interpretation of the tectonic structure of the Magura Nappe in the south-western part of the Gorce Mts is presented. The division of the so-called Periklippen Fold Zone is no longer justified in the light of the geological investigations described above, supported by the age of the lithostratigraphic units, so now it is included in the Turbacz Thrust Sheet. In this way, the research of the present authors confirmed some earlier observations (e.g., Cieszkowski in Cieszkowski and Olszewska, 1986; Cieszkowski, 1992, 1995) and is compatible with the results of the Nowy Targ PIG-1 deep borehole (Paul and Poprawa, 1992). In the Orava-Nowy Targ Basin and its surroundings between Jabłonka and Ludźmierz, Struska (2008) did not notice the thrust, interpreted by Watycha (1976b, 1978). In the light of all these statements, the deep-sea Miocene deposits of the Turbacz Thrust Sheet tectonically make direct contact with the Pieniny Klippen Belt. Detailed geological mapping, partly supported by the age of the lithostratigraphic divisions, helped the authors also to distinguish the Kudłoń Thrust Sheet. It was treated previously as being a uniform unit of the Turbacz Thrust Sheet (Watycha in Burtan *et al*., 1978a, b).

Current research indicates the relatively steeply dipping deposits of the Krynica Subunit. Additionally, the zones of overturned back layers with southern vergence were determined (layers dipping to the N in an inverted position; Fig. 3). A similar structural plan also was noted in the Gorce Mts (Watycha, 1975; Watycha in Burtan *et al*., 1978a), as well as in the Slovak part of Orava (Marschalko and Potfaj, 1982; Teťák *et al*., 2016a). The occurrence of these phenomena is associated with a flower structure (e.g., Golonka *et al*., 2005), formed in the collision zone, where the North European Platform was subducted beneath the Inner Carpathian terrain. During this process, deposits of the Outer Carpathian Flysch basins were folded and uprooted from their basement, forming imbricated nappes, overthrusted on the platform.

The southern part of the Turbacz Thrust-Sheet in the Dunajec River valley is covered by the Neogene and Quaternary fresh-water deposits of the intra-mountain Orava-Nowy Targ Basin, the formation of which began about 14–15 Ma (Cieszkowski, 1995; Baumgart-Kotarba, 2001), with subsidence of 0.05–0.12 mm/year, determined on the basis of the thickness of the surface and subsurface fill (Zuchiewicz, 1995). The fill is about 950 m thick in the borehole Czarny Dunajec IG-1 (Watycha, 1977) and the total thickness of the Neogene and Quaternary deposits significantly exceeds 1,000 m (Cieszkowski and Struska, 2009). In the eastern part of the basin in the Frydman area, the fill exceeds 120 m (Niedzielski, 1971). The development of the Orava-Nowy Targ Basin is associated with a clear lowering of the southern and south-western slopes of the Gorce Mts, as well as the southern slopes of the Orava-Jordanów Foothills, which border the Gorce Mts in the west (Watycha, 1976a, 1977; Zuchiewicz, 1995). The southern fragment of the study area, along with the Dunajec River valley, is within the northern range of the Orava-Nowy Targ Basin in geomorphological terms. However, the fill of the basin is south of the tectonic boundary beyond the study area.

Comments on sedimentation

The Cretaceous–Lower Miocene Krynica and Bystrica subunits in the study area are made up of deep-sea gravity flow deposits, derived from the ridge bounding the Magura Basin to the south (e.g., Teťák *et al.,* 2019; Teťák, 2022). They contain typical deep water agglutinated foraminifera, with a small addition of redeposited calcareous taxa, showing signs of transportation. In the Malcov Fm, Cretaceous and Paleocene redeposited species are especially numerous. Cieszkowski (1992, 1995) also mentioned older foraminifera in the Miocene flysch, overlying the Malcov Fm.

According to the model by Walker (1978), the analysed deposits represent the upper and middle parts of a deep-sea fan, while the more proximal parts are not preserved here. The deposits representing the lower part of the middle fan and the lower fan can be observed in the sedimentary sequence of the Bystrica Subunit. The transport directions from the Krynica Subunit point to asymmetrical fans, with lobes expanding to the west and north-west, less frequently to the north and north-east directions, and only in exceptional cases to the east (Fig. 4). Perhaps this arrangement was associated with the dip of the basinal axis westwards. Particularly, the low-density currents, depositing the thin- and medium-bedded sandstone or/and sandstone-shale facies, matched this latest direction.

According to the classification by Stow (1986), the classes of facies from A to D, and exceptionally class F (Fig. 4) are recognized in the study area. In this classification, class A means conglomerates and conglomerate sandstones, B primarily sandstones, C sandstones and mudstones, D siltstones and mudstones, in which fine-grained sandstones can be found, while class F represents the rocks, composed of exotic clasts, and deposits with disturbed stratification. The sedimentological features of the sedimentary sequence of the Krynica Subunit exposed in the field are represented primarily by facies A2.7, A2.8, B2.1 and B2.2, as well as C2.1, C2.2, C2. 3 and C2.4 (Fig. 4). Facies D2.3 appears to a limited extent. In some places, facies F1 points to small submarine slumps. Facies C2.2 and C2.3 are found in the Ropianka Fm, as well as the B2.1 thick-bedded packets, and a smaller number of disordered facies A1.7 and A1.8. The facies C2.2 and C2.3, and in smaller quantities D2.3 are found in the Beloveža Fm, and B2.1 and B2.2 as well as A2.7 and A2.8 occur in the Krynica Sst Mbr. The Piwniczna Sst Mbr is dominated by C2.1 and C2.2 facies, as well as B2.1 and B2.2, the disordered B1.2 facies are less frequent, the A2.8 facies plays a big role, and the flysch interbeds represent facies C2.3 and D2.3. The Kowaniec Mbr is dominated by C2.2, C2.3 and B2.1, and shale packets within it by facies D2.3, and the single layers of the Łącko Marl facies represent facies C2.4. The uppermost division of the Magura Fm, the Poprad Sst Mbr, is dominated by facies B2.1, C2.1 and C2.2. The Malcov Fm is dominated by facies C2.3, with a smaller contribution of facies C2.4, while facies C2.1 and C2.2 as well as B2.1 were noticed in the thick-bedded sandstone packages.

Comments on an alimentary area

The palaeocurrent directions and the petrographic composition of the sandstones and conglomerates indicate that the source area of the Ropianka Fm and younger formations was located at the southern margin of the Magura Basin (Oszczypko *et al.,* 2015, 2016) on the ridge, which separated the basin from the basins of the Pieniny Klippen Belt region (Oszczypko *et al.*, 2005b, 2015). The ridge had to be relatively wide, with a complex geological structure and morphology (Oszczypko *et al.*, 2015). This may be evidenced by the great thickness of the Late Cretaceous to Early Miocene deposits of the Krynica Subunit, which reaches 3,500–4,000 m. A large amount of coarse- and medium-grained sandstones and conglomerates may indicate significant denivelation in this area. These denivelations stimulated intensive erosion of the ridge area in question and transport of the material making up the ridge, which was later supplied by gravity flows into the Magura Basin.

The petrographic composition of the sandstones and conglomerates points to the geology of the ridge, which was composed of a crystalline massif with a granitoid core, a metamorphic mantle and a sedimentary cover. The petrographic composition of the Magura Fm becomes more varied towards the top. The detritic material (quartz, feldspar and muscovite as well as grains and clasts of crystalline rocks in the sandstones of the Ropianka Fm) was derived initially from the crystalline massif. The presence of feldspars in the Magura Fm at about 10% (Białoń, 2006) and the granitoid grains indicate intensive erosion of a crystalline body, composed of plutonic rocks. Sedimentary rock grains are rare or absent in the lower part of the formation but are significantly frequent upwards as a result of intense erosion inland of the ridge. The petrographic composition of the rocks indicates that the material came from the recycled orogen (Białoń, 2006), which contained a lot of metamorphic rocks. The presence of the chromites in the heavy minerals indicates the presence of ultramafic rocks. These may be associated with ophiolites in the source area (Cieszkowski *et al.*, 1998b), but it is difficult to determine the orogenesis, with which the ultramafics were associated (Schnabel in Cieszkowski *et al.*, 1998b). It seems most likely that they are associated with the Variscan orogenesis, although the Alpine orogenesis cannot be excluded. Large blocks of ultrabasit rocks were found at Osielec in the more outer Rača Subunit of the Magura Nappe. It was regarded as an Alpine ophiolite (Wieser, 1952), but radiometric dating proved its Neoproterozoic age (Cieszkowski *et al.*, 2017).

A sedimentary cover was developed on the crystalline rocks. It included 1) Triassic rocks of the Early Triassic Werfenian quartzites, debris of which is common in the Magura Fm sandstones and conglomerates, 2) Middle Triassic limestones and dolomites, in which numerous clasts are present in the upper part of the Poprad Sst Mbr and more abundantly in the Malcov Fm. There are also limestone clasts from the Jurassic–Cretaceous transition and from the Early Cretaceous Urgonian facies.

The grains of volcanic rock in sandstones of the Magura Fm could have been derived from intrusions (?Permian) in the discussed ridge. The geological structure of the ridge shows some analogies to the Tatra Mountains or other Central Carpathian massifs in northern Slovakia. During the Paleogene, sedimentation of the carbonates with algae-bryozoan reefs took place on the shelf of the ridge. This is evidenced by the presence of fragments of coralline algae and bryozoans, as well as crumbs of mollusc shells. The large foraminifers found in the sandstones of the Magura Fm or Malcov Fm also were derived from the shelf (Bieda, 1946; Świdziński, 1961a, b; Watycha, 1975, 1976a).

CONCLUSIONS

The Ropianka Fm, Krynica Sst Mbr, Beloveža Fm, Piwniczna Sst Mbr, Kowaniec Mbr and Poprad Sst Mbr, Magura Fm, Waksmund Sst Mbr, Malcov Fm were distinguished in the Late Cretaceous–Early Miocene sedimentary succession of the Krynica Subunit and the Maszkowice Sst Mbr, the Mniszek Sh Mbr, and the Trusiówki Mbr in the Bystrica Subunit of the Magura Nappe in the Gorce Mountains. This article presents their lithological and micropalaeontological characteristics. In general, the divisions follow the formal lithostratigraphic scheme by Birkenmajer and Oszczypko (1989) and Oszczypko (1991). However, the traditional divisions, Ropianka Fm and Beloveža Fm were restored, in place of the Szczawnica Fm and the Zarzecze Fm, respectively.

In the Krynica Subunit, two tectonic units of a lower order are proposed, the revised Turbacz Thrust Sheet and the newly distinguished Kudłoń Thrust Sheet. It was confirmed that the Peri-Klippen Fault Zone (in a range of thrust-sheets) *sensu* Watycha (1975, 1976a), which previously was located in the southern part of the study area, does not exist.

The folds in the study area, with the exception of the Rdzawka-Obidowiec Anticline, have rather small amplitudes. Most of them are local and it is not easy to track their axes over a longer distance. Only some of them have longer fold axes, which continue beyond the boundary of the research area, e.g., the Sieniawa Syncline and the Pyzówka (Buflak Fold) Anticline or the Rdzawka-Obidowiec Anticline.

Two zones with differently oriented fault strikes occur in the study area, the western zone, with domination of the NNW–SSE- and NNE–SSW-oriented faults and the eastern zone, where in addition to the NNW–SSE and NNE–SSW directions, also the NE–SW- oriented faults occur. In the second zone, the ENE–WSW faults also were recognized occasionally. Some faults form fault systems zones, which often continue beyond the research area, e.g., Waksmund-Ponice Fault System.

The flysch deposits of the Krynica and Bystrica subunits were deposited by gravity flows in the deep sea in the southern part of the Magura Basin. The alimentary area was located on the ridge, bounding the Magura Basin in the south. The composition of the sandstones and conglomerates indicates that the core of the ridge consists of crystalline rocks and sedimentary strata, composed of Mesozoic and Cenozoic rocks. In the composition of sandstones and conglomerates, the Triassic detritic and carbonate rocks play an important role.

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