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Campanian–Paleocene Jaworzynka Formation in its type area (Magura Nappe, Outer Carpathians)

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ABSTRACT:

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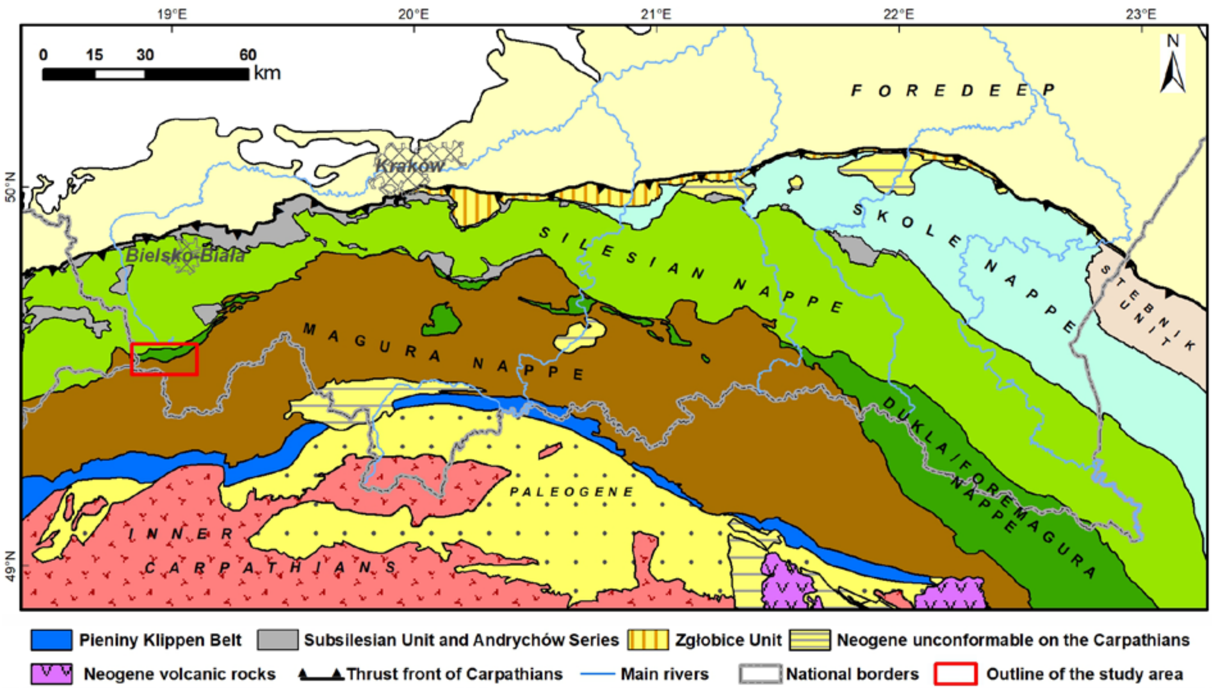
The Campanian–Paleocene Jaworzynka Formation, a part of the Magura Nappe succession in the Polish Outer Carpathians, is described in terms of its detailed litho- and biostratigraphy. The formation stretches along the marginal part of the Siary Unit, from the Jaworzynka stratotype area in the Silesian Beskid Mts up to the Mszana Dolna area in the Beskid Wyspowy Mts. Its equivalent in the Moravskoslezské Beskydy Mts of the Czech Republic is the Soláň Formation. In the stratotype area, the formation displays complex structure. We distinguish four lithological units, i.e., Biotite Sandstone and Shale (I), Shale (II), Mutne Sandstone Member (III) and Thin-bedded Turbidite (IV) and provide the first detailed biostratigraphy of particular units. The first unit forms the most prominent part of the formation. It was deposited in the Middle Campanian–earliest Maastrichtian within the upper part of *Caudammina gigantea* Zone up to the lower part of the *Rzehakina inclusa* Zone. The second unit occurs only locally and its age is limited to the Maastrichtian, to the *Rzehakina inclusa* Zone. The third unit is composed of thick-bedded sandstones that in some parts may form more than the half of the total thickness of the formation. It is Late Maastrichtian–Danian in age and is placed in the upper part of the *Rzehakina inclusa* Zone and the lower part of the *Rzehakina fissistomata* Zone. It is usually covered by a thin package of thin-bedded turbiditic sandstone and shales of Danian–Thanetian age with foraminifera of the *Rzehakina fissistomata* Zone.

Key words: Upper Cretaceous; Paleogene; Lithostratigraphy; Foraminifera; Biostratigraphy.

INTRODUCTION

Lithostratigraphy is based on the distinguishing more or less consistent but individual rock divisions. Such a division introduces order and systematizes, in effect, it facilitates any subsequent geological research. The lithostratigraphy created for a regional scale causes some difficulties in connection with the lateral facies variability of the distinguished units which is a direct reflection of depositional conditions.

According to the rules of the Polish Stratigraphic Code (Alexandrowicz *et al*. 1975; Racki and Narkiewicz 2006) each lithostratigraphic unit refers to the stratotype, as the pattern for comparison and as the place where the unit was described and widely documented. One of the lithostratigraphic units in the Outer Carpathian Magura Nappe is the Jaworzynka Formation. The formalization process evolved from the first description of the rock bodies and their age estimation (Sikora and Żytko 1960) up to the com-



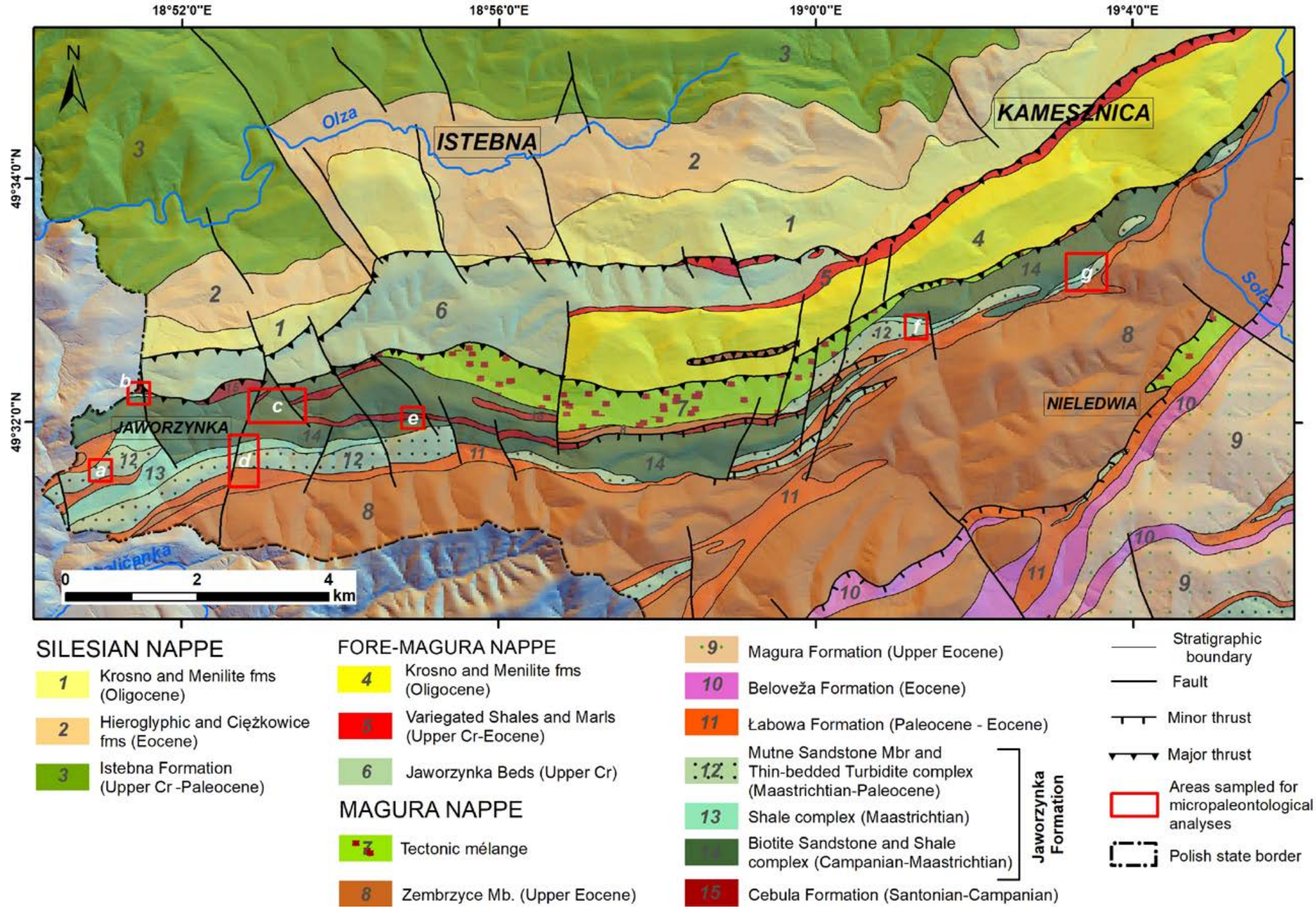
Text-fig. 1. Geological sketch map of the Western Carpathians (based on Żytko *et al.* 1989, modified) showing their main structural units and regional context of the study area.

plete formalization (Oszczypko *et al.* 2005). This formalization was based mainly on the characteristics of the reference sections located in the Beskid Wyspowy area, about one hundred km from the type area in the Silesian Beskid Mts (Oszczypko *et al.* 2005). The type area was not very precisely located as the "Marginal part of the Magura Nappe, SW of Żywiec". The present research was conducted in the area of Jaworzynka village in the Silesian Beskid Mts that is the exact stratotype area of the Jaworzynka Formation. The main purpose of this paper is, first of all, the presentation of the detailed lithostratigraphy of this formation in the type locality, where the internal structure is quite complex, secondly, the comparison of the stratotype area with other areas at the marginal part of the Magura Nappe, and finally, the precise determination of the formation's age.

GEOLOGICAL SETTING

The study area is located in the Carpathians, which are an orogenic mountain chain originated in Miocene age (Text-fig. 1). The northern part of the Carpathians constitutes the Outer Carpathians having a nappe structure. The Western Outer Carpathians, which occur in Polish territory, are built of the Skole, Silesian and Subsilesian nappes and the Foremagura group of nappes and they are partly covered by the biggest and structurally highest Magura Nappe. These nappes consist of Jurassic up to Miocene sedimentary rocks mostly of deep-water origin. The nappes are thrust over each other and together over the European Platform, which forms the basement.

The study area is located within the marginal part of the Magura Nappe. In this Nappe and the adjacent part of the Pieniny Klippen Belt, several zones are distinguished, which originated within the Magura Basin (e.g., Koszarski *et al.* 1974; Ślączka *et al.* 2006; Golonka *et al.* 2019a, b). From the north these are Siary, Rača, Bystrica, Krynica, Maruszyna and Hulina zones. This division is due to differences in lithology reflecting variable sedimentary conditions within the Magura Basin, but it is also emphasized by the main tectonic structures formed as a result of folding and thrusting of the basin deposits. That is why the zones are regarded as tectono-facies units (e.g., Sikora and Żytko 1960; Węcławik 1969;



Text-fig. 2. Geological map of the study area with detailed sampled areas marked with a–g rectangles: a – Wawrzeczów Groń hill, b – Olecka creek, c and d – Czadeczka creek, e – Kocurzenka hamlet, f – Suche hamlet, g – Szare village. Based on Burtan *et al*. (1956, 2017), Burtan (1973a), significantly changed according to authors study.

Książkiewicz 1974a, b; Teťák 2008). The paleogeographic reconstruction assumes the occurrence of the Magura Basin as a part of the Alpine Tethys (e.g., Golonka and Krobicki 2004; Oszczypko 2006; Schmid *et al.* 2008; Oszczypko and Oszczypko-Clowes 2009; Puglisi 2009; Golonka *et al.* 2019a, b and references therein). The Magura Basin existed from the Jurassic up to the Miocene and it was separated by the Czorsztyn Ridge from the other parts of Alpine Tethys. The accretionary wedge formed in the front of the Czorsztyn Ridge. From the north, the Magura Basin together with the Foremagura Basin was bordered by the Silesian Ridge that separated them from the northern Silesian domain basins. According to Tet'ák *et al.* (2019) the first two basins were separated by the Fore-Magura Ridge. The northern part of the Magura Basin and its sedimentary cover is distinguished as the marginal Siary Zone (*sensu* Koszarski *et al.* 1974). The rocks which are the subject of this study belong to this zone.

The study area is located in the southwestern part of the Polish Carpathians, in the Silesian Beskid Mts in Jaworzynka area, close to the Polish/Czech/Slovak state boundary, 25 km south west of Bielsko-Biała city. The geological observations were conducted in Jaworzynka village and its surroundings, where the stratotype area for the Jaworzynka Formation is located (Text-fig. 2). They concentrated on the Upper Cretaceous and the Lower Paleogene deposits of the Magura Nappe.

PREVIOUS STUDIES ON THE JAWORZYNKA FORMATION

Turbidite deposits, rich in biotite and feldspar, are the most characteristic rocks of the Jaworzynka Formation. They were described for the first time by Sikora and Żytko (1960) from the Siary Zone of the Magura Nappe and from the Foremagura group of nappes within the Beskid Żywiecki and Beskid Makowski Mts. Sikora and Żytko (1960) paid attention to two sedimentary complexes of thick-bedded sandstones occurring one after the other but differing in lithological features. The dominance of distinctive greenish thick-bedded sandstones passing into conglomerates with glauconite, feldspar, biotite and carbonate cement was characteristic of the lower complex. The first biostratigraphical estimations based on foraminifera suggested a Late Cretaceous–Paleocene age (Sikora and Żytko 1960). These deposits were named the Biotite-feldspar Beds due to the characteristic mineral components of the sandstones. They were associated with the Inoceramian Beds widespread in the Magura Nappe (e.g., Świdziński 1947; Bieda *et al.* 1963). The second distinguished complex of thick-bedded sandstones rich in feldspars was named the Mutne Sandstone (Sikora and Żytko 1960). This name comes from Mutne village located in the Beskid Makowski Mts. It was introduced in consultation with Jadwiga Burtan who at the same time was doing geological mapping in the Jeleśnia area where these beds were well exposed. Later this area was chosen as the stratotype for the Mutne Sandstone Member (Cieszkowski *et al.* 2006, 2007). Sikora and Żytko (1960) described the Mutne Sandstone as an Upper Cretaceous–Lower Eocene complex of thick-bedded sandstones and conglomerates with feldspars.

The name "biotite facies" was also applied in the Carpathian lithostratigraphy. It was commonly used as a lithostratigraphic unit that was distinguished in several areas of the northern zones of the Magura Nappe in the western part of the Polish Carpathians (e.g., Burtan *et al.* 1956, 1964; Żytko 1962; Burtan 1964a; Burtan and Skoczylas-Ciszewska 1964a, b; Burtan and Szymakowska 1964; Nowak 1964; Sikora 1964; Watycha 1964). This term was used regarding Upper Cretaceous beds with biotite-rich sandstones but commonly in a broader sense for the Cretaceous–Paleocene deposits of the "Inoceramian-type" containing biotite and occurring below the Paleogene variegated shales that later were distinguished as the Łabowa Shale Formation (e.g., Oszczypko 1991; Cieszkowski and Waśkowska-Oliwa 2001; Cieszkowski *et al.* 2006, 2007). In the marginal part of the Magura Nappe in the Jaworzynka area, the biotite facies occurring between variegated shale complexes was distinguished as the cartographic unit (Burtan 1964b).

During the preparation of the geological map covering the Jaworzynka area, Burtan (1973a, b) proposed the following stratigraphic scheme for the Cretaceous–Paleocene deposits: (1) the Jaworzynka Biotite Beds of Senonian age, corresponding to the first complex described above and consisting mainly of thin- and medium bedded sandstones with glauconite, feldspar and mica interbedded by shales, (2) the Inoceramian Beds, Maastrichtian in age, built of sandstones, shales, fucoid marls and rare sphaerosiderites, (3) the Dark Shale, which is a locally occurring unit of Danian age, including black and grey shales and rarely fucoid marls as well, and (4) the Łyska Sandstone (terminological equivalent of the Mutne Sandstone – see Cieszkowski *et al.* 2007) comprising thick-bedded sandstones of Paleocene age. This informal set of units is under- and overlain by variegated shales. This stratigraphic scheme gave a broad basis for the formal lithostratigraphy.

The Jaworzynka Formation was established as a formal lithostratigraphic unit during formalization of the Rača Zone of the Magura Nappe by Oszczypko *et al.* (2005). It is one of the formations within the Mogielica Group. The marginal part of the Magura Nappe SW of Żywiec was proposed as stratotype. The description of the lithology was given according to the reference sections located in Półrzeczki, Jurkowa creek and Koninki in the Mszana Dolna area in the Beskid Wyspowy and Gorce Mts (Oszczypko *et al.* 2005). According to this description the Formation is heterogeneous and consists of two complexes, i.e., (1) a lower complex of thick-bedded sandstones and conglomerates that are intercalated by shales, with biotite and glauconite as characteristic components of sandstones, (2) an upper complex of thick-bedded muscovitic sandstones. These complexes were described from the Półrzeczki, Jurkowa creek where their total thickness is about 200 m. A much thinner sequence of rocks assigned by Oszczypko *et al.* (2005) to the Jaworzynka Formation is exposed in a second reference section in Koninki village located southwards of the previous one. It reaches only a few meters in thickness and includes mostly thick-bedded sandstones, some of which containing glauconite. Oszczypko *et al.* (2005) placed the Jaworzynka Formation between the older thin-bedded turbidites of the Białe Formation and younger thin- to medium-bedded turbidites of the Ropianka Formation covered by variegated shales of the Łabowa Shale Formation and estimated its age as Middle Campanian–Early Maastrichtian. The Jaworzynka Formation was also acknowledged in the description of the Siary Zone lithostratigraphy in the Sucha Beskidzka surroundings by Cieszkowski *et al.* (2006, 2007) and Golonka *et al.* (2013). However, these authors included the Mutne Sandstone and Gołynia Shale in this formation. The last shale complex was first differentiated as an individual lithostratigraphic unit by Burtan (1973a, b) and named the black shales, while in the Sucha Beskidzka area Książkiewicz (1974b) proposed to distinguish similar deposits as the Gołynia Shale. Cieszkowski *et al.* (2006) assigned them to the Jaworzynka Formation as a member and subsequently formalized also the Mutne Sandstone as a member of this Formation (Cieszkowski *et al.* 2007). In such an approach, the Jaworzynka Formation encompasses deposits of the Senonian to Paleocene time span and it is bordered at the bottom by the Cretaceous red shales of the Cebula Shale Formation (Golonka and Wójcik 1978b; Pivko 2002), or the Malinowa Shale Formation (according to Oszczypko *et al.* 2005) and covered by Paleocene to Eocene red shales belonging to the Łabowa Shale Formation (Oszczypko 1991). The biostratigraphical research in the Jaworzynka area and surrounding areas was based on the foraminifera group of fossils and were conducted by Blaicher (in Sikora and Żytko 1960), Morgiel, Liszkowa, Geroch and Bieda (in Burtan 1973b) and Malata (1981).

MATERIAL AND METHODS

Our research is based on study of outcrops and detailed biostratigraphical analyses. Geological observations included geological mapping in the Jaworzynka area (Text-figs 1, 2), where the Upper Cretaceous and Paleocene deposits were marked on archive maps (Burtan 1973a), and determination of the lithological variability of these deposits and the logging of continuous sections, usually exposed in river-bed or banks. Foraminiferal biostratigraphy was applied due to the common occurrence of adequate microfossils. The foraminifera were separated from shales. Rock samples of 0.5 kg weight were taken during the field work. Samples were macerated in an aqueous solution of Glaubert's salt by multiple cooling and heating the solution. The next stage involved washing material through 0.63 mm mesh-size sieves and separation of the foraminiferal tests from the residue obtained. Mostly agglutinated foraminifera occurred in the studied deposits; very rare calcareous benthic foraminifera were noted, i.e., only a few specimens in some samples. Samples were collected from different complexes of the Jaworzynka Formation distinguished in the field as well as from the over- and underlying formations of variegated shales (Text-fig. 2). Twenty-nine samples contained a paleontological record that enabled determination of age, whereas 10 samples were barren. The Table 1 presents the taxonomical composition of particular samples, which was basis for the biostratigraphical age determination. The zonation based on agglutinated foraminifera after Olszewska (1997) was used. A whole sequence of zones from Campanian up to Lower Eocene was distinguished, allowing the age determinations of all lithological complexes in the study area. The paleontological material will be deposited in the collection of the European Micropaleontological Reference Centre of the Micropress Europe Foundation (Kraków, Mickiewicza 30, Poland).

RESULTS

Lithology

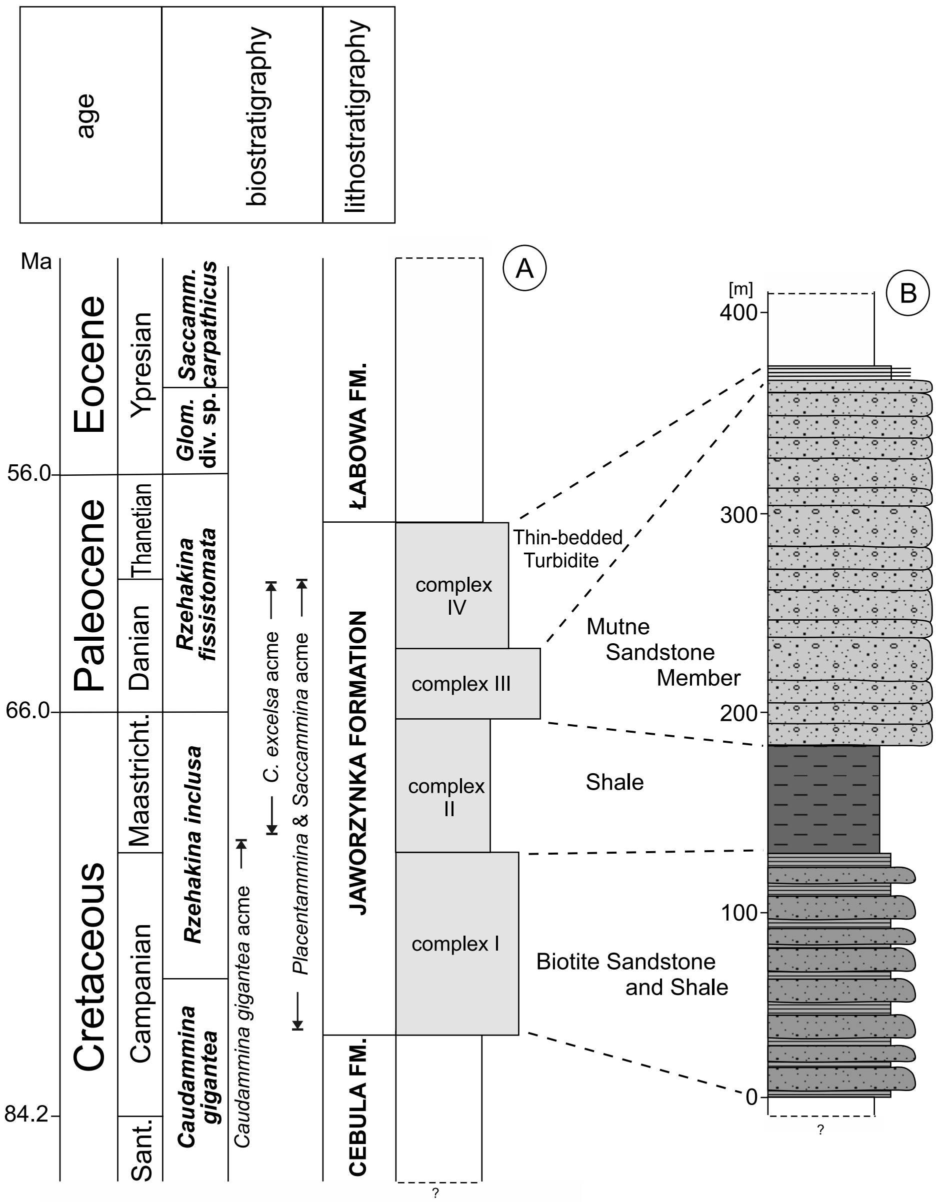
The oldest deposits of the Magura Nappe in the most western part of the Outer Carpathians are represented by variegated shales that are included in the **Cebula Shale Formation** (Golonka and Wójcik 1978a, b; Ryłko *et al.* 1992; Pivko 2002; Cieszkowski *et al.* 2007). More to the east in the Beskid Wyspowy Range this part of the Magura succession was distinguished by Birkenmajer and Oszczypko (1989) and Oszczypko *et al.* (2005) as the Malinowa Shale Formation. In general, it is a complex predominantly composed of shales, red and green in colour, usually clayey and non-calcareous. Intercalations of harder marly shales are very rare. Very thin-bedded, fine-grained siliceous sandstones occur sporadically. The complex reaches from a few up to tens of meters in thickness. In the Jaworzynka area this complex underlies turbidite-type deposits composed of sandstones, conglomerates and shales, although with dominance of the first lithology (Text-figs 3, 4A). These deposits are in turn covered by another complex of variegated shales belonging to the Paleocene–Eocene Łabowa Shale Formation (Oszczypko 1991) (Text-fig. 3). Taking into account the lithological character as well as the vertical and lateral variability of the turbidite-type deposits, we include the whole sequence encompassed between Cretaceous and Paleogene complexes of variegated shales to the **Jaworzynka Formation** as it was proposed by Cieszkowski *et al.* (2006).

The direct contact of this formation with the underling Cebula Shale Formation is currently not exposed in the studied sections. However, based on the observations of Burtan (1973a, b) and Sikora and Żytko (1960) it can be assumed that the boundary between these formations is sharp and that the first package of biotite sandstones representing the lower part of Jaworzynka Formation occurs directly above the variegated shales. On the basis of individual lithological character, four complexes can be distinguished within this Formation that can be regarded as its members.

Biotite Sandstone and Shale (Text-figs 3, 4B, C). This is the lowermost lithological complex of the Jaworzynka Formation. It is predominated by very thick- to medium-bedded sandstones, e.g., some of the layers reach up to 3 m in thickness. They are interlayered by thin-bedded shales or by decimetres to a few metres packages of thin-bedded sandstone-shale interbeddings. Fine- and medium-grained sandstones prevail; coarse-grained or conglomeratic sandstones occur as well but are less frequent. Coarser sandstones are massive or graded. Coarse grains and sometimes even granules occur in the bottom part of normally graded layers that towards the top pass into fine-grained parallel or convolute laminated sandstones. Thin- and medium-bedded sandstones are usually entirely laminated. Soles of sandstone beds are usually sharp and covered with flute casts or trace fossils. Sandstones are polymictic, dominating by quartz but containing also numerous feldspars, glauconite grains and mica flakes. Muscovite is particularly abundant, but the occurrence of biotite in the form of relatively big flakes is a characteristic feature of these sandstones that distinguishes them from the other Upper Cretaceous sandstones in the Magura Nappe, belonging to the Ropianka and Szczawina formations. The sandstones occur in packages or individual layers gradually passing upwards into shales. The interbeddings of shale range from a few up to several cm in thickness; occasionally thicker intervals occur. These shales are dark grey or greenish-grey in colour, usually clayey and non-calcareous. Very thin layers of black shales with pyrite also can be encountered. Moreover, there are thin intervals of massive, dark-coloured mudstone rich in plant detritus and containing concretions. The thickness of the whole complex of Biotite Sandstone and Shale in the Jaworzynka area reaches up to 150 m. The Jaworzynka Beds unit defined by Burtan (1973a, b) originally referred exclusively to this complex.

Shale (Text-figs 3, 4D, E). About 30 m thick complex of shales lies above the Biotite Sandstone and Shale complex. The lower boundary is gradual but the transitional interval is short. Within this unit, dark grey, bluish and greenish muddy, non-calcareous shales dominate. Shale beds are usually entirely bioturbated. They are intercalated by thin and very thin layers of brown or dark grey marly shales with limonitic covering on weathering surfaces. Rarely, very thin-bedded parallel laminated quartz sandstones with muscovite and feldspars and thin layers of fucoid marls are also present. Within some muddy layers sphaerosiderites occur as well.

Mutne Sandstone Member (Text-figs 3, 5A, B). The next complex is built mainly of thick- and very thick-bedded sandstones where individual layers reach usually between 35 and 120 cm in thickness. They are rarely intercalated by thin-bedded sandstones and thin layers of shales. The lower boundary



Text-fig. 3. Bio- and lithostratigraphical divisions of the Jaworzynka Formation in the stratotype area and its relation to the under- and overlying formations. Sant. – Santonian, Maastricht. – Maastrichtian. A – age of the Jaworzynka Formations divisions and underlying and overlying formations; B – column illustrating different lithology of Jaworzynka Formation and their thickness.

of the complex is usually sharp, especially at the contact with the Shale complex, although the latter occurs only locally. The complex begins with a package of porous sandstones, some of which have high-density turbidite character. Some layers indicate amalgamation that results in multiplication of their thickness. In general, rocks of this Member are grey and grey- to light-brown on weathered surfaces. Most of them are built of medium- and coarse-grained sandy material, but on the other hand, conglomeratic sandstones or fine-grained sandstones are quite common as well. There are also layers of granule conglomerate. Both lithologies, the sandstones and conglomerates show massive structure or are graded with horizontal, convolute, rarely with cross-lamination at the uppermost part of layers. The bottom part of the graded sandstones usually is coarse-grained and often contains gravel-sized clasts. At the bottom surface of layers

Text-fig. 4. Photographs of the Campanian–Maastrichtian deposits in Jaworzynka area. A – Cebula Shale Formation (Klimki hamlet in Jaworzynka village); B–E – Jaworzynka Formation including: B–C – the Biotite Jaworzynka Sandstone (complex I, Zapasieki Górne hamlet in Jaworzynka village; c area on Text-fig. 2); D–E – Jaworzynka Shale (complex II, Krężelka creek in Jaworzynka village; d area); F – fucoid marls from complex II (Krężelka creek in Jaworzynka village; d area).

flute-casts and load-casts are observable. Quartz is the main component of sandstones and conglomerates, they are also relatively rich in feldspar and muscovite, rarely biotite occurs. The heterogeneous sand-

Text-fig. 5. Photographs of the Maastrichtian–Paleocene deposits in Jaworzynka area. A–C – Jaworzynka Formation: A – Mutne Sandstone Member (Szare; f area on Text-fig. 2); B – conglomeratic sandstone of the Mutne Sandstone Member (Wawrzeczów Groń hill; a area); C – Jaworzynka thin-bedded turbidites (complex IV, Szare; g area); D – Łabowa Shale Formation (Krężelka creek in Jaworzynka village, d area).

stones also contain glauconite giving them a greenish tint if abundant, although usually the amount of glauconite is rather small. Gravel material is represented also by fragments of metamorphic rocks, sedimentary shales (rip-up clasts), marls and limestones. These rocks often constitute the largest and most distinctive grain component. Some sandstone layers contain numerous rip-up clasts in their lowermost part. Thin, up to few cm, layers of dark grey shales rich in muscovite and plant detritus intercalate sandstone packages or individual sandstone layers. Infrequently, laminated mudstones including very-thin bedded sandstones occur as interbeddings up to 50 cm in thickness. The total thickness of the Mutne Sandstone Member reaches up to 180 m.

Thin-bedded Turbidite (Text-figs 3, 5C). The Mutne Sandstone Member is overlain by a few m thick complex of thin-bedded turbiditic deposits. Their boundary is gradual but the transitional interval is short. This complex is built of grey and greenish-grey mudstones and very fine- up to medium-grained grey, quartz sandstones containing also mica and pyrite. The sandstone layers are very thin to medium in thickness and their amount does not exceed 30% of the total thickness of this unit. Horizontal and wavy lamination is typical for deposits of this complex. The bottom surfaces of layers are frequently covered with flute-casts and trace fossils, and mudstones are often entirely bioturbated.

Sandstone deposits belonging to the Łabowa Shale Formation (Text-figs 3, 5D) (Oszczypko 1991; Cieszkowski *et al.* 2006, 2007) overlie the Jaworzynka Formation. The formations' contact is distinctive and is marked with the first package of red shales that designates the beginning of Łabowa Shale Formation. Red, reddish, grey and green variegated shales are its main components, although red shales generally prevail. The variegated shales form a laminated multi-coloured sequence, while at some sections the shales are more homogeneous with a gradual transition to multi-colour variations. Very thin bedded laminated sandstones and rare massive marls occur as intercalations between shaly packages.

Biostratigraphy

Samples collected from the sedimentary complexes distinguished above that contained foraminifera contributed to the age determinations of particular divisions of the Jaworzynka Formation (Text-figs 6, 7, Table 1). Using the benthic foraminiferal zonation after Olszewska, (1997) three biozones were distinguished (Text-fig. 3) and characterized. The alphabetical list of foraminifera species mentioned in the paper is given in the appendix.

Caudammina gigantea Zone –
partial range acme zone

AGE: Late Santonian–Early Campanian.

DIAGNOSTIC FEATURE: Numerous specimens of *Caudammina gigantea* co-occur with *Caudammina ovulum*; upper boundary is indicated by the first occurrence of *Rzehakina inclusa*. Lower boundary is unknown in the studied section.

CHARACTERISTICS: Low taxonomical diversity characterizes the foraminiferal assemblages. The tubular forms, *Paratrochamminoides* div. sp. and *Recurvoides* div. sp. are most numerous taxa. Abundant *Caudammina gigantea* co-occur with specimens of *Caudammina ovulum*.

OCCURRENCE: Cebula Shale Formation.

Rzehakina inclusa Zone – total range zone

AGE: Late Campanian–Maastrichtian/Paleocene boundary

DEFINITION: interval between the first and last occurrence of *Rzehakina inclusa*.

DESCRIPTION: *Rzehakina inclusa* co-occur with different number of specimens of *Caudammina gigantea*, *Caudammina excelsa* and *Caudammina ovulum*. Other typical accompanying foraminifera, like *Glomospira diffundens*, *Rzehakina epigona*, *Rzehakina minima*, *Annectina grzybowskii*, *Remesella varians*, *Hormosina velascoensis*, *Buzasina pacifica* and *Spiroplectammina spectabilis* are present in single specimens, mainly in the upper part of the zone. Particularly numerous are *Placentammina placenta*, *Saccammina grzybowskii* and in some samples *Karrerulina coniformis*. Occurrence of the big-sized (over 0.7 mm) specimens of *Glomospira glomerata* (Text-fig. 6M) and *Glomospira* ex. gr. *irregularis* (Text-fig. 6O) is the other typical feature. In the topmost part the co-occurrence *Rzehakina inclusa* and *Rzehakina fissistomata* is possible.

LOWER BOUNDARY: The *Rzehakina inclusa* Zone was firstly distinguished by Olszewska (1997) as the acme zone that was based on the abundant occurrence of the index taxa. *Rzehakina inclusa* (Text-fig. 7I) ranges from the Late Campanian up to end of the Maastrichtian (Morgiel and Olszewska 1981; Olszewska 1997; Waśkowska *et al.* 2019). It belongs to the cosmopolitan forms (Kaminski and Gradstein 2005), but its appearance is not common. Study of continuous sections suggests that *Rzehakina inclusa* occurs quite irregularly (e.g., Bąk 2004; Oszczypko *et al.* 2005; Cieszkowski *et al.* 2007; Waśkowska *et al.* 2019). If it is present, it occurs as single specimen or up to a few specimens in rather numerous and highly diversified assemblages. This evanescence of *Rzehakina inclusa* results from its environmental requirements. It is found in deep-water foraminiferal assemblages, which developed in favourable ecological conditions, in rather low-energy environments

Text-fig. 6. Images of the agglutinated foraminifera from the Jaworzynka Formation in the stratotype area. **A** – *Rhabdammina linearis*; **B** – *Psammosiphonella cylindrica*; **C** – *Nothia exelsa*; **D** – *Nothia* sp.; **E** – *Bathysiphon* sp.; **F**–**G** – *Placentammina placenta*; **H** – *Saccammina grzybowskii*; **I**–**J** – *Ammodiscus tenuissimus*; **K** – *Ammodiscus peruvianus*; **L** – *Glomospira charoides*; **M** – *Glomospira glomerata*; **N** – *Glomospira diffundens*; **O** – *Glomospira* sp.; **P**–**R** – *Annectina grzybowskii*; **S**–**T** – *Caudammina gigantea*; **U**–**W** – *Caudammina ovulum*.

rich in nutrients. Higher energetic environments limit the occurrence of *Rzehakina inclusa*. Therefore, the biostratigraphical position of the lowermost part of Biotite Sandstone and Shale (complex I) is discussable. 5 out of 6 samples have some features of the *Caudammina gigantea* Zone. Opportunistic forms, mostly *Nothia* with the admixture of other tubular forms, are present. *Caudammina gigantea* (Text-fig. 6S, T) constitutes a significant component of these samples. *Caudammina ovulum* (Text-fig. 6U, W) and *Caudammina excelsa* (Text-fig. 7A, B) co-occur in single specimens. There are some indications that

Sampled section (location presented on Text-fig. 2) →	a	b	c						d							e		f						g					
Lithostratigraphy →	Complex III	Complex II	Complex I						Complex II						Łabowa Fm.	Cebula Fm.	Cebula Fm.	Complex II	Complex III			Complex IV	Łabowa Fm.	Complex II		Complex IV		Łabowa Fm.	
Sample No. → ↓ Taxonomical list	108/3/07	106/1/07	240/6/17	239/5/17	238/4/17	237/3/17	236/2/17	235/1/17	108/1/06	109/2/06	110/3/06	111/4/06	112/5/06	113/6/06	95/1/06	109/4/07	110/5/07	8/3/08	9/4/08	10/5/08	11/6/08	15/10/08	13/08/08	104/3/07	105/4/07	101/07	103/2/07	102/07	61/1/06
Ammodiscus cretaceus		I		II	II	I			II	II	III	III	II		I	III	I	III	III	IIII	III	I	III	II	III				I
Ammodiscus peruvianus					IIII	I			IIII	II	I	IIII	IIII			I		III	II	I				III	V				I
Ammodiscus planus					I	I			V	V	III	II	VV					IIII	II				II	I	II			I	
Ammodiscus pennyi					I				I																				
Ammodiscus tenuissimus		I			III				I	II			II					II	III	I	I		I		II				
Ammodiscus sp.		I								II											I			I					
Ammolagena clavata																			I	I	I					IIII			I
Ammosphaeroidina pseudopauciloculata		III			III				IIII	IIII	V	IIII	II		III			V	V	IIII	IIII	IIII	III	IIII	VV	II		II	
Annectina biedai																									II	I		II	
Annectina grzybowskii										I		III	IIII		II			I	I		III					I		I	I
Aschemocella div. sp.			II	II	I	I				I			I						I	II		I	I	III	III	I		I	
Bathysiphon and *Nothia* div. sp.	X	X	XX	X	L	L	IIII	XX	L	L	XX	XX	L	XX	X	XX	IIII	XX	XX	XX	V	VV	V	VII	L	IIII	IIII	V	
Caudammina excelsa	VV				I			I	X	VV		VV	V					IIII	III	V	VV			I		I			
Caudammina gigantea		III	I	II	VV	II	I	I	I	I			I			V	I			II				II	III				
Caudammina ovulum	III			I	IIII	I	III		V	IIII	II	II	VV			IIII	I	III	IIII	IIII	X			IIII	V				I
Caudammina ovloides	III																				I								I
Cribrostomoides subglobosus		I			I				III	IIII	I	III	V						III	IIII	I		IIII	I	I	III			
Cystammina sp.																IIII		IIII								I			
Dorothia intendata													I																
Dorothia trochoides												I																	
Eratidus gerochi																							I						
Glomospira charoides					I		IIII		II	II	II	IIII	II		X			III	III	III	I	I	V			I		X	II
Glomospira diffundens									I	I	I	I	III					I	II		I			I		I			I
Glomospira glomerata									I			I	IIII		IIII					I	I	II	IIII			II		I	
Glomospira gordialis		III					II		I	III	I	IIII			IIII	II	I		III	I	III		III	III	III	I		IIII	I
Glomospira irregularis s.s.									IIII	II	I	III			I			II	II	I				I	III	I		I	
Glomospira ex gr. *irregularis*		I			I		I				I	I	III			II			I	III	I		IIII	III	V	I		I	III
Glomospira serpens											I		I					I			I	I							
Haplophragmoides eggeri									I	I	I	III	I								I					I			
Haplophragmoides kirki				I	I		I			I		II	I			I		I			III	I	I					III	I
Haplophragmoides horridus									I									I							I				

Sampled section (location presented on Text-fig. 2) →	a	b	c						d							e		f						g					
Lithostratigraphy →	Complex III	Complex II	Complex I						Complex II						Łabowa Fm.	Cebula Fm.	Cebula Fm.	Complex II	Complex III			Complex IV	Łabowa Fm.	Complex II		Complex IV		Łabowa Fm.	
Sample No. → ↓ Taxonomical list	108/3/07	106/1/07	240/6/17	239/5/17	238/4/17	237/3/17	236/2/17	235/1/17	108/1/06	109/2/06	110/3/06	111/4/06	112/5/06	113/6/06	95/1/06	109/4/07	110/5/07	8/3/08	9/4/08	10/5/08	11/6/08	15/10/08	13/08/08	104/3/07	105/4/07	101/07	103/2/07	102/07	61/1/06
Haplophragmoides walteri						I						I			III				I		II	I	I					I	I
Haplophragmoides majtliukae																										I			I
Hormosina velascoensis									I	I		I	III		I				I	III	II				I	I			
Hormosina sp.					I								II			I					I								
Hyperammina elongata and *H. dilata*	III				I								I		I														
Kalamopsis grzybowskii					IIII	I			I	I							II			I						II			IIII
Karrerulina conversa	V			I							III	V	V		L	I		V	IIII	IIII	III		IIII	I					
Karrerulina coniformis												III	X		I	I		IIII	II	V			I	V	V				I
Karrerulina horrida	III		I																		I		III		III				
Lituotuba lituiformis											I		I								I								
Nodosaria spp.														I								I							
Paratrochamminoides acervulatus									I																	I			
Paratrochamminoides contortus					IIII		I	II	III	IIII	III	IIII	V	IIII	VV						III			III	II	I	I	I	
Paratrochamminoides deflexiformis										IIII	I	I	IIII													I			
Paratrochamminoides dubius													II																
Paratrochamminoides gorayskii									I	I	I	II	III		II										I				
Conglophragmium irregularis			III						IIII	IIII	III	IIII	IIII	I	V									V	V	I		I	
Paratrochamminoides heteromorphus					II				I	I			I		II											I		I	
Paratrochamminoides multilobus									I																			I	
Paratrochamminoides mitratus					I		I		III	I	I		IIII		I											I			
Paratrochamminoides olszewskii					IIII				IIII	III	II	II	II	I	III											II		I	
Paratrochamminoides uviformis										II	I		II											II	II				
Paratrochamminoides and *Trochamminoides* div. spp.		IIII			IIII	II		I	III						II	V	III	V	X	X	VV	II	VV	IIII	V	II		II	VV
Placentammina placenta		VV			V	III	II	I	IIII	V	V	VV	V	I	IIII	IIII	II	IIII	IIII	VV	I	I	III	IIII	V	IIII		III	II
Psamosphaera sp.					I				I			I	I			I				I	I								I
Recurvoides div. sp. and *Thalmannammina* div. sp.	I	IIII			IIII	III	XX	I	VV	VV	V	V	X	IIII	XX	VV	II	VV	V	IIII	V	III	X	V	X	IIII	I	V	V
Remesella varians									I				IIII																
Reophax duplex					III				I	II	I	III	III						II	II			II	I		I		II	
Reophax elongatus																												I	
Reophax plana								I	I	I	I		II						I	II			III	II	IIII	I			
Reophax nodulosus									II																	I			

Sampled section (location presented on Text-fig. 2) →	a	b	c						d							e		f						g					
Lithostratigraphy →	Complex III	Complex II	Complex I						Complex II						Łabowa Fm.	Cebula Fm.	Cebula Fm.	Complex II	Complex III			Complex IV	Łabowa Fm.	Complex II		Complex IV		Łabowa Fm.	
Sample No. → ↓ Taxonomical list	108/3/07	106/1/07	240/6/17	239/5/17	238/4/17	237/3/17	236/2/17	235/1/17	108/1/06	109/2/06	110/3/06	111/4/06	112/5/06	113/6/06	95/1/06	109/4/07	110/5/07	8/3/08	9/4/08	10/5/08	11/6/08	15/10/08	13/08/08	104/3/07	105/4/07	101/07	103/2/07	102/07	61/1/06
Reophax trinatinensis									I		I	II	III												IIII				
Reophax sp. (*guttifer*)-type											I		I		I									II	II				
Rhabdammina and *Psammosiphonella* div. sp. (mainly *P. cylindrica*) and *Rhizammina indivisa*	VV	IIII	V		X		III	V	L	XX	XX	L	L	VV	L			VV	VV	IIII	I	III	V	V	X	VV		I	
Rzehakina epigona	III				I								I								I			I					
Rzehakina inclusa		I			I				I	II			I							I				II	II				
Rzehakina minima		I								I		I	I								I							I	
Rzehakina lata																				I						I			
Rzehakina fissistomata																					I				I	I			I
Saccammina scabrosa									III	III	I	I	IIII	II												I			
Saccammina grzybowskii			III	I	IIII				IIII	II								IIII	V	I	IIII			III	VV	II		II	
Spiroplectammina dentata										I																			
Saccamminoides carpathicus																							II						
Spiroplectammina spectabilis									I																	II			
Subrepohax scalarias					IIII				I			II	I					III	IIII	I			III	I	IIII	I			
Subrepohax pseudoscalaris												I	IIII						I	II	I			I	IIII	I		I	I
Trochammininopsis altiformis										I									I	II									
Trochammina bulloidiformis									I																				
Trochammina globigeriniformis											I							I	I	II			I	I		I			
Trochammina quadriloba																										I			
Trochammina sp.	III	III										I						I		I			II	I	II	I		I	
Trochamminoides flolius													I																
Trochamminoides coronatus and *T. subcoronatus*			I						III		I		I		III											I		I	
Trochamminoides grzybowskii									II	I	I		I						II							I			
Trochamminoides proteus										I	I		I			II										I			
Trochamminoides variolarius									III	IIII	III	III	IIII						II					I		I	I	I	
Calcareous benthic foraminifera *Gyroidines*–*Eponides* morphotypes																				I		I						I	
Fish tooth					I																I		I	I					
Radiolaria																III		IIII		II				V	IIII				III

Table 1. Distribution of foraminifera in the studied sections. Explanations: I: 1–4 specimens, II: 5–9 specimens, III: 10–19 specimens, IIII: 20–49 specimens, V: 50–99 specimens, VV: 100–199 specimens, X: 200–399 specimens, XX: 400–999 specimens, L: 1000 specimens and more.

Text-fig. 7. Images of the agglutinated foraminifera from the Jaworzynka Formation in the stratotype area. **A**–**B** – *Caudammina excelsa*; **C** – *Kalamopsis grzybowskii*; **D** – *Subreophax scalaris*; **E** – *Reophax plana* Halkyard; **F** – *Reophax* cf. *plana*; **G** – *Rzehakina* sp.; **H** – *Rzehakina minima*; **I** – *Rzehakina inclusa*; **J**–**K** – *Rzehakina fissistomata*; **L** – *Paratrochamminoides* sp.; **M** – *Ammosphaeroidina pseudopauciloculata*; **N** – *Trochammina* cf. *globigeriniformis*; **O** – *Remesella varians* – juvenile form; **P** – *Spiroplectammina spectabilis*; **R** – *Karrerulina conversa*; **S** – *Karrerrulina coniformis*; **T** – *Recurvoides anormis*; **U** – *Recurvoides nucleolus*; **W** – *Thalmannammina subturbinata*.

these samples do not include microfossil assemblages truly representative of the biostratigraphic estimations: (1) they contain a low number of foraminifera and (2) within the continuous sequences of complex I, between samples poor in foraminifera, samples with more diversified assemblages occur that show features typical of a younger zone. The 238/4/17 sample was taken from the lower/middle part of complex I. Besides numerous *Caudammina gigantea*, *Rzehakina inclusa* specimens are present that clearly indicate the *Rzehakina inclusa* Zone (Table 1). It should be noted that this sample was taken from a unique 1.5 m thick package of layers within the Biotite Sandstone and Shale complex consisting of light grey and greenish-grey mudstones intercalated by a few layers of dark grey mudstones. The character of these deposits indicates that they were probably deposited in conditions more favourable for foraminifera development. The other samples came from typical mudstone layers, which are darker in colour and much thinner. Taking into account the infrequent foraminifera and the low taxonomical diversity, usually up to a few species, as well as the presence only of cosmopolitan and opportunistic forms in the remaining samples from the Biotite Sandstone and Shale (Table 1) we assume a low biostratigraphical value of the preserved foraminifera. Therefore, based on the sampled material, it is not possible to indicate the precise boundary between the *Caudammina gigantea* and *Rzehakina inclusa* zones in the studied section. The underlying variegated shales of the Cebula Shale Formation contain numerous, more diversified foraminifera with an abundance of *Caudammina gigantea*; 80 specimens in 0.5 kg mudstone sample no. 104/9/09. This assemblage refers to the real *Caudammina gigantea acme* Zone.

UPPER BOUNDARY: The *Rzehakina inclusa* Zone defined by Olszewska (1997) was distinguished as the Upper Campanian–base Paleocene interval zone. The first occurrence of *Rzehakina inclusa* determines the lower, while the first occurrence of *Rzehakina fissistomata* determines the upper boundary of this zone (Olszewska 1997). In the present work, the *Rzehakina inclusa* Zone is considered as a total range zone, designated by the occurrence of the marker species. In the sample no 105/4/07, together with *Rzehakina inclusa*, a small specimen of *Rzehakina fissistomata* was recognized (Table 1). This latter specimen is a good indicator of the Paleocene (Bieda *et al.* 1963; Geroch *et al.* 1967; Jurkiewicz 1967; Jednorowska 1975; Morgiel and Szymakowska 1978; Morgiel and Olszewska 1981; Geroch and Nowak 1984; Bubík 1995; Malata *et al.* 1996; Olszewska 1997; Bubík *et al.* 1999; Oszczypko *et al.* 2005). However, the co-occurrence of these species is also known from the Subsilesian Nappe, from Upper Maastrichtian strata. They occur together with planktonic foraminifera *Abathomphalus mayroensis* (Cieszkowski *et al.* 2000) that is indicative of the latest Maastrichtian. Bubík *et al.* (1999) reported *Rzehakina fissistomata* with Late Maastrichtian nannofossils and *Abathomphalus mayroensis* from the Soláň Formation of the Rača Zone in the Magura Nappe.

BIOSTRATIGRAPHY INSIDE THE ZONE: Sample 238/4/17 from the Biotite Sandstone and Shale contains numerous *Caudammina gigantea* (104 specimens) co-occurring with few specimens of *Rzehakina inclusa* and *Rzehakina epigona* (Table 1). This composition is typical for lower part of the *Rzehakina inclusa* Zone that in the Outer Carpathians lasted from the Campanian up to earliest Maastrichtian (Malata *et al.* 1996; Waśkowska *et al.* 2019). The disappearance of mass occurrences of *Caudammina gigantea* coincides with a significant increase of taxonomic differentiation of benthic agglutinated foraminifera in the Carpathian basins. New taxa appear in the assemblages. *Glomospira diffundens*, *Spiroplectammina spectabilis*, *Remesella varians*, *Annectina grzybowskii*, *Hormosina velascoensis* have their first occurrences (e.g., Jednorowska 1975; Morgiel and Olszewska 1981; Olszewska 1997; Kaminski and Gradstein 2005; Waśkowska *et al.* 2014). An assemblage structure including these species co-occurring with *Rzehakina inclusa* is typical of the upper part of the *Rzehakina inclusa* Zone, Early Maastrichtian–Maastrichtian/Paleocene in age. The typical feature of most of the assemblages studied from that interval is a significant increase (acme?) of *Caudammina excelsa* and *Placentammina placenta*, *Saccammina grzybowskii*, and in part of the samples numerous occurrence of *Caudammina ovulum*. *Caudammina excelsa*–*Rzehakina inclusa* beds were mentioned by Pokorny (1960) from Moravia. The common occurrence of *Caudammina excelsa* was noticed in the Magura Nappe from Lower Paleocene deposits (Waśkowska *et al.* 2018), from Campanian–Maastrichtian (Malata 2002) and from Maastrichtian–Lower Paleocene deposits (Malata *et al.* 1996). Olszewska (1980) and Bąk (2004) indicate similar asemblages from other Outer Carpathian areas. The abundant occurrence of *Placentammina placenta* has a broader stratigraphic range. Hanzlíková (1983) draws attention to the stratigraphic significance of *Placentammina placenta* and described the *Placentammina placenta* dominated assemblages from the Moravian Paleocene. Beckmann *et al.* (1982) and Waśkowska *et al.* (2018) found assemblages rich in these taxa in the Paleocene, whereas Geroch (1960) and Bąk (2004) found them in the Late Cretaceous and Paleocene. The acme of *Placentammina placenta* is clearly marked in the Maastrichtian and has a continuation in the Paleocene in the Jaworzynka Formation.

OCCURRENCE: Lower? and middle part of the Jaworzynka Formation from the Biotite Sandstone and Shale (complex I) up to the middle/upper part of the Mutne Sandstone Member (complexes I–III) (Text-fig. 3). The Biotite sandstone and shale (I) contains mainly an infrequent and poorly-diagnostic fauna, only one sample giving a good biostratigraphical record on the basis of numerous and diversified species. Foraminifera in this sample are typical for the lower part of *Rzehakina inclusa* Zone with numerous *Caudammina gigantea* of Middle Campanian–earliest Maastrichtian age. The lower part of the Biotite Sandstone and Shale complex could belong to the *Caudammina gigantea* Zone or to the lower part of the *Rzehakina inclusa* Zone.

Samples taken from the thin-bedded complex between the Biotite Sandstone and Shale and the Mutne Sandstone Member (complex II) contain rich and diversified assemblages. Taking into account the occurrence of biostratigraphical markers, they refer to the upper part of *Rzehakina inclusa* Zone of Early Maastrichtian–Maastrichtian/Paleocene age. Sample no 105/4/07 with *Rzehakina inclusa* and *Rzehakina fissistomata* (Table 1) was taken a few metres below the Mutne Sandstone Member.

Some samples taken from the Mutne Sandstone Member (III) in the Jaworzynka area (not included in Table 1) do not give clear biostratigraphical results. They are barren or contain a non-characteristic long-ranged cosmopolitan fauna of Cretaceous–Paleocene age. An assemblage typical of the upper part of the *Rzehakina inclusa* Zone occurs in sample no. 10/5/08 (Table 1) which was taken from the middle/upper part of the Mutne Sandstone Member. Samples no. 108/3/07 and 9/4/08 (Table 1) coming from the lower part of the Mutne Sandstone Member contain numerous *Hormosina excelsa*. The high number of *Hormosina excelsa* together with their position in the section allows establishment of a Maastrichtian age. A good biostratigraphical record was noticed at the stratotype section in Mutne village (Jeleśnia area) (Cieszkowski *et al*. 2007).

Rzehakina fissistomata Zone – partial range zone

AGE: Paleocene.

DEFINITION: Interval between the last occurrence of *Rzehakina inclusa* and the last occurrence of *Rzehakina fissistomata*, the occurrence of *Haplophragmoides mjatliukae* is an additional indicator, the upper boundary coincides with *Glomospira* div. sp. acme.

DESCRIPTION: Index taxa co-occur with *Annectina grzybowskii*, *Rzehakina epigona*, *Rzehakina minima*, *Hormosina velascoensis*, *Spiroplectammina spectabilis*, *Annectina biedai*, *Caudammina ovula* and *Glomospira diffundens*.

BIOSTRATIGRAPHY INSIDE THE ZONE: The sequence of samples taken from the upper part of the Mutne Sandstone Member up to the lower part of the variegated shales of the Łabowa Shale Formation contains assemblages with *Rzehakina fissistomata*. The taxonomical composition of the assemblages is similar, and they differ in the participation of individual species. Numerous specimens of *Caudammina excelsa*, *Caudammina ovulum*, *Placentammina placenta* and *Saccammina grzybowskii* occur in the lower part. Their mass occurrence is a continuation from the Maastrichtian deposits. Numerous *Placentammina placenta* are common in the Lower Paleocene, they were noticed by Geroch (1960), Jurkiewicz (1967), Beckmann *et al.* (1982), Hanzlíková (1983) and Bąk (2004). The occurrence of a high number of *Caudammina* in Lower Paleocene deposits in the Magura Nappe is common; particularly abundant are *Caudammina ovulum* (Jurkiewicz 1967; Waśkowska *et al*. 2018) and *Caudammina excelsa* (Malata *et al.* 1996). Because of the high number of *Caudammina*, the Danian deposits from the Subsilesian Nappe were described as a *Caudammina* association (Waśkowska-Oliwa 2008). Therefore, the numerous occurrences of *Caudammina excelsa*, *Caudammina ovulum*, *Placentammina placenta* and *Saccammina grzybowskii* in the studied section may be indicative of the Danian. In the Thanetian assemblages, the number of *Caudammina* significantly decreases and this species is rare or absent (Bąk 2004; Waśkowska-Oliwa 2005; Waśkowska-Oliwa 2008); similarly, *Annectina grzybowskii* and *Glomospira diffundens* occur occasionally. The taxonomic diversity is low; cosmopolitan forms, mainly tubular forms, *Paratrochamminoides* and *Recurvoides* are present next to *Rzehakina fissistomata* (Bąk 2004; Waśkowska-Oliwa 2008). This assemblage was recognized in samples from the upper part of Paleocene section. A decrease in size of foraminifera is observed in the upper Paleocene samples. The common foraminifera like *Paratrochamminoides*, *Trochamminoides*, *Recurvoides*, *Ammodiscus*, *Karrerulina* and *Glomospira* occur as smaller specimens in comparison with Danian samples. For comparison, *Glomospira charoides* is two times bigger in the Lower Paleocene samples.

The dwarf agglutinated foraminiferal associations are known from the Lower Eocene *Glomospira* div. sp. Zone *sensu* Olszewska (1997). In the Outer

Carpathian basins, assemblages with abundant *Glomospira charoides* and *Glomospira gordialis* are common (e.g., Jurkiewicz 1967; Jednorowska 1968; Morgiel and Szymakowska 1978; Morgiel and Olszewska 1981; Rajchel 1990; Bubík 1995; Malata *et al.* 1996; Waśkowska-Oliwa 2000; Bąk 2004; Cieszkowski *et al.* 2011; Waśkowska 2011a, b and references therein). They are typical post-crisis assemblages in deep water environments (e.g., Speijer *et al.* 2012; Arreguín-Rodrîguez *et al.* 2013; Giusberti *et al.* 2016 and references therein). This crisis started in the Paleocene and it is known as Late Paleocene Thermal Maximum (Kennet and Scott 1991). The Paleocene dwarf assemblage from Jaworzynka area could reflect this episode.

OCCURRENCE: The uppermost part of the Mutne Sandstone Member (complex III) with package of the thin-bedded turbiditic deposits above (complex IV); the lower part of the Łabowa Shale Formation (Text-fig. 3).

Only one sample gives a Paleocene biostratigraphical record from the upper Mutne Sandstone Member. The abundant *Caudammina* together with *Placentammina placenta* and *Saccammina grzybowskii* occurring within this member places this part of the section in the Lower Paleocene.

The thin-bedded package of flysch deposits above the Mutne Sandstone Member and the lower part of the variegated shales of the Łabowa Shale Formation contain assemblages with *Rzehakina fissistomata* with single *Caudammina* and *Placentammina* indicating a Late Paleocene age. The biostratigraphical control of the overlying variegated shales indicates an Early and Middle Eocene age on the basis of foraminiferal assemblages typical of the *Glomospira* div. sp. acme Zone, the *Saccamminoides carpathicus* total range Zone and the *Reticulophragmium amplectens* partial range Zone.

DISCUSSION

Lithostratigraphic remarks

The lithologies of the Jaworzynka Formation described above are characteristic for the western part of the marginal zone of the Magura Nappe in the Polish Outer Carpathians. The thin- or medium-bedded turbiditic facies (known as the Inoceramian or Ropianka facies) occurring between the variegated shale complexes constitutes the background in which two thick sandstone-dominated complexes occur. The typical feature is an occurrence of oligomictic sandstones where, besides to dominant quartz, a significant amount of feldspar and mica is present. Mica flakes are both muscovite and biotite. While the muscovite is quite a common component of other formations of the Magura Nappe, the significant occurrence of biotite is characteristic especially of the Jaworzynka Formation. This was highlighted in distinguishing of the Inoceramian-type facies in the western part of the Magura Nappe as the biotite facies (e.g., Burtan *et al.* 1956; Żytko 1962; Burtan 1964a; Burtan and Skoczylas-Ciszewska 1964a, b; Nowak 1964; Sikora 1964; Watycha 1964; Książkiewicz 1974a, b; Chodyń 2002; Cieszkowski *et al.* 2006) or biotite beds, biotite-feldspar beds or biotite sandstones (e.g., Bieda *et al.* 1963; Geroch *et al.* 1967; Książkiewicz 1974a, b; Golonka and Wójcik 1978a, b; Cieszkowski 1992; Ryłko and Paul 2014). The amount of biotite decreases towards the top of the formation. The lower parts are the most rich and contain quite large biotite flakes. The lowermost sandstone-dominated complex of the Biotite Sandstone and Shale (I) visually has the largest amount of biotite. Burtan (1978) and Golonka and Wójcik (1978b) noted the occurrence of "rubellan". Higher up, biotite is present, but rather as a subordinary component in relation to the feldspars and muscovite. That is why the Mutne Sandstone Member was earlier referred to as feldspar sandstones or arkose sandstones (e.g., Książkiewicz 1974a, b; Cieszkowski *et al.* 2007).

Oszczypko *et al.* (2005) emphasized the heterogeneous lithology of the Jaworzynka Formation in the Rača Zone. The change of lithology marks the boundary between two members. The biotite-rich sandstone-dominated complex occurs in the lower part and the thick-bedded sandstone complex with muscovite occurs higher up. Considering the rock bodies with dominant thick layers, such a system is found in the stratotype area, where complexes *sensu* Oszczypko *et al.* (2005) adequately refer to the Biotite Sandstone and Shale (complex I) and Mutne Sandstone Member (complex III). Taking into account (1) the internal lithological consistency of the Biotite Sandstone and Shale (complex I); (2) presence of unequivocal features typical of it, (3) clearly specified boundaries and (4) lateral distribution, it would be advisable in accordance with the rules of the Polish Stratigraphic Code (Alexandrowicz *et al.* 1975; Racki and Narkiewicz 2006) to establish this as a formal lithostratigraphic unit at a member level. The Jaworzynka area, where the history of the lithostratigraphy of the Cretaceous Magura Nappe deposits have a long tradition, documentation and quite good outcrops meets all requirements for establishing a stratotype here.

The lithology of the Jaworzynka Formation is variable, both laterally and vertically. In the area of the Silesian and Żywiecki Beskid Mts, the Biotite Sandstone and Shale or/and Mutne Sandstone Member form thick complexes while their thickness decreases to the east. Finally, in the middle part of the Polish Carpathians the first complex pinches out and is replaced by the Inoceramian-type facies subsequently defined as the Ropianka Formation (Ślączka and Miziołek 1995; Teťák *et al.* 2017), i.e., thin bedded sandstones and shales that do not contain characteristic biotite flakes. Sandstones that are assigned to the Mutne Sandstone Member have a wider distribution than the Biotite Sandstone and Shale complex. They crop out more to the east and are noted in the vicinity of Gorlice (Sikora 1967; Kopciowski *et al.* 2014) within the upper part of the Inoceramian Beds. However, this member does not form a continuous lithosome, e.g., slightly east of the Jaworzynka area it is replaced by the Biotite Sandstone and Shale complex (Sikora and Żytko 1960). The shaly-dominated complex II was distinguished by Burtan (1973a, b) as the Inoceramian beds of Maastrichtian age. It is developed only locally and its thickness does not exceed 30 m. Complex IV is even thinner and reaches only a few meters in thickness. It also occurs locally in the Jaworzynka and Jeleśnia areas. In case of its absence the Mutne Sandstone Member is in direct contact with the Late Paleocene variegated shales of the Łabowa Shale Formation (Cieszkowski *et al.* 2007).

The Jaworzynka-type strata continue into Czech and Slovak territory, where they are named as the Soláň Formation (e.g., Matějka and Roth 1949; Matějka and Roth 1956; Pesl 1968; Švábenická *et al.* 1997; Potfaj *et al.* 2003; Mello *et al.* 2005; Picha *et al.* 2006; Teťák 2008; Golonka *et al.* 2013). The different names are inherited from the second half of the 20th century, when lithostratigraphic nomenclature was established independently in Poland and former Czechoslovakia. To the west, the thickness of the Soláň Formation in the Siary Zone, increases. The biotite-rich sandstones building the lower part of the Soláň Formation in the Tri Kameny Zone are significantly thicker; the lower part itself reaches 500 m in thickness (Švábenická *et al.* 1997). The formation in the outer Rača Zone is up to 1000 m thick (Picha *et al.* 2006; Teťák 2008; Teťák *et al.* 2019). This data refers to average or maximum thickness, which vary locally. Teťák (2008) and Tet'ák *et al.* (2019) indicate that the massive prograding wedge, which forms the Soláň Formation, developed along the northern margin of the Magura Basin and was fed by several sources that resulted in the formation of several overlapping small-sized fans.

The Soláň Formation is underlain by the Kaumberg Formation (equivalent of the Cebula Shale Formation) and covered by the Beloveza Formation (*sensu* Matějka and Roth 1956; Mahel 1968; Picha *et al.* 2006; Golonka *et al.* 2019b). However, the lower part of Beloveza Formation in this meaning corresponds to the Łabowa Shale Formation of Polish territory (e.g., Świdziński 1947; Węcławik 1969; Bogacz *et al.* 1979; Švábenická *et al.* 1997; Picha *et al.* 2006; Golonka and Waśkowska 2012). The subdivision of the Soláň Formation is based on its position within the facies zone in the Magura Basin during the Late Cretaceous–Paleocene (Švábenická *et al.* 1997). The Tri Kameny lithofacies zone of the Rača unit distinguished in the Czech Republic is an equivalent of the Siary Zone in Poland and the outer Rača unit in the Slovak Republic (Teťák 2008). The Soláň Formation is subdivided into the Raztoka and Lukov members (Švábenická *et al.* 1997; Potfaj *et al.* 2003; Mello *et al.* 2005; Picha *et al.* 2006; Teťák 2008). The Raztoka Member is composed of sandstones abundant in biotite interbedded with shales (Picha *et al.* 2006) and corresponds to the lower part of Jaworzynka Formation in the Silesian Beskid and Żywiecki Beskid Mts in Poland. It is subdivided into two lithofacies: the Sandstone-claystone (sandstone predominating) and the Claystone-sandstone (thin-bedded turbidites) (Pesl 1968). The upper Lukov Member is composed mainly of thick-bedded sandstones and conglomerates and it is an equivalent of the Polish Mutne Sandstone Member (Teťák 2008).

In the studied area, the Jaworzynka Formation of the Magura Nappe corresponds with the Jaworzynka Beds (Formation) of the Foremagura Nappe. Preliminary lithostratigraphical and biostratigraphical analyses point to similarities, particularly to the lower part of Jaworzynka Formation of the Magura Nappe (complexes I and II). This resemblance results from a common sedimentation history during the Late Cretaceous. The isolation of the Foremagura Basin in this part of the Carpathian Basin took place at the end of the Cretaceous, which was a little later in relation to the eastern area of the Western Outer Carpathians (Golonka *et al.* 2019). The first clear signs of separation of the Foremagura Basin from the Magura Basin are marked in the sedimentary record in the Early Paleocene or perhaps in the latest Cretaceous.

Biostratigraphical remarks

The sampled section from the Cebula Shale Formation, through the Jaworzynka up to the Łabowa Shale Formation contains agglutinated foraminifera. Using foraminiferal biostratigraphy, the total stratigraphic range of the Jaworzynka Formation in the stratotype area extends from the Middle Campanian up to the Late Danian (Text-fig. 3). Obtained data from under- and overlying formations confirm this age. Some inaccuracies are connected with the age estimation of the lower boundary of the Jaworzynka Formation. They result from the poor foraminiferal record. Due to the non-characteristic fauna with low biostratigraphical value, the exact position of the Formation within the biozonal scheme cannot be clearly specified and precisely assigned to the *Caudammina gigantea* or the *Rzehakina inclusa* zones. From the lowermost parts of the Biotite-feldspar Beds (complex I), Sikora and Żytko (1960) mentioned assemblages of agglutinated foraminifera particularly rich in *Caudammina gigantea* and with numerous *Caudammina ovulum* that suggests these beds belong to the *Caudammina gigantea* Zone. Therefore, the Biotite Sandstone and Shale (complex I) contains the Middle Campanian–lowermost Maastrichtian foraminifera characteristic of forms of the upper part of the *Caudammina gigantea* Zone and the lower part of the *Rzehakina inclusa* Zone. The overlying shale-dominated thin-bedded turbiditic deposits (complex II) contain assemblages with *Rzehakina inclusa* and accompanying taxa typical of the upper part of the *Rzehakina inclusa* Zone of early Maastrichtian–Maastrichtian/Paleocene age. The co-occurrence of *Rzehakina inclusa* and *Rzehakina fissistomata* in the topmost part suggests the latest Maastrichtian age. The first occurrence of *Rzehakina fissistomata* was found within the uppermost Cretaceous planktonic *Abathomphalus mayaroensis* Zone (Bubík *et al.* 1999; Cieszkowski *et al.* 2000). This age is consistent with the arrangements of Burtan (1973a, b). The age of the Mutne Sandstone Member (III) was discussed by Cieszkowski *et al.* (2007). It was estimated as being either Late Maastrichtian or Paleocene. The Late Maastrichtian age was assigned based on foraminifer biostratigraphy, but the superposition proves a Paleocene age. Foraminiferal assemblages with *Rzehakina fissistomata* characteristic of the Lower Paleocene were obtained from the Mutne Sandstone Member in the Jaworzynka area. It seems that the stratigraphic range of the Mutne Sandstone Member is shorter. According to the age estimations of the topmost part of complex II, the base of the Mutne Sandstone Member is Late Maastrichtian in age, and at least the half of this sandy-conglomerate complex was deposited before the end of the Cretaceous. It is not younger than the Lower Paleocene, although the upper boundary of the Mutne Sandstone Member is not precisely determined. The Cretaceous/Paleocene boundary occurs in the upper part of the Mutne Sandstone Member. The complex IV forming the topmost part of the Jaworzynka Formation as well as the lower part of the Łabowa Shale Formation contains foraminifera of Late Paleocene age (Text-fig. 3).

These age estimations correspond with the general age of the Biotite facies and the Upper Senonian–Paleocene in more eastern region of the Siary Zone (*sensu* Nowak 1964; Żytko 1963; Burtan 1964a; Sikora 1964). The Soláň Formation being the western continuation of the Jaworzynka Formation is more or less age-consistent also. According to the studies of Švábenická *et al.* (1997) and Bubík *et al.* (1999), the lower boundary of the Soláň Formation ranges from the Late Campanian to the Early Maastrichtian. The calcareous nannofossils from the lowermost part of this Formation from Valašské Meziříčí locality, situated close to the northern boundary of the the Magura Nappe, indicate the upper CC 22 nannofossil zone of the Late Campanian (Švábenická *et al.* 1997). The upper boundary of the Soláň Formation and the base of Beloveza Formation are situated within the Danian on the basis of agglutinated foraminifera (Bubík *et al.* 1999). This boundary is located a little bit earlier in relation to data from the Jaworzynka Formation stratotype area.

The Jaworzynka Formation in the Rača Zone in the Beskid Wyspowy and Gorce Mts ranges from Middle Campanian to Early Maastrichtian (Oszczypko *et al.* 2005). However, the biotite-rich sandstones occurring in the most northern part of the Magura Nappe diminish towards its inner parts in favour of thin-bedded turbiditic deposits that are defined in this region as a separate Ropianka Formation of Maastrichtian–Paleocene age. The influence of the biotite facies in the more inner part of the Magura Nappe decreases and in the Late Maastrichtian and Paleocene, Inoceramian-type deposits distinguished as the Ropianka Formation are significantly more important. The pinching put of the Jaworzynka sandstone wedge to the south towards the inner Rača Zone and the replacement of it by the distal thin-bedded flysch sediments of the Sandstone-claystone lithofacies is observed in the Slovak Outer Carpathians as well (Pesl 1968; Teťák 2008, 2017).

The zonation based on agglutinated foraminifera according to Olszewska (1997) was used for this study.

The sequence of samples refers to the succession of the foraminiferal zones. For the Upper Cretaceous deposits of the Magura Nappe, biostratigraphical divisions from the North Atlantic were used. The *Caudammina gigantea* Local Abundance Zone (Campanian–Early or Middle Maastrichtian) and the *Remesella varians* Local Interval Zone (Early/Middle–Late Maastrichtian) were distinguished by Malata *et al.* (1996) and Oszczypko *et al.* (2005). This stratigraphic scheme could give more precise data for the Maastrichtian interval, especially use of the *Remesella varians* Zone. Difficulties result from the limited occurrence *Remesella varians*. It occurs sporadically and was found only in 2 samples 108/1/06 and 112/5/06 (Table 1) taken from the thin-bedded flysch deposits between the Biotite Sandstone and Shale and the Mutne Sandstone Member.

In the studied assemblages, abundant occurrences of some taxa were used for biostratigraphy (Text-fig. 3). The *Caudammina gigantea* acme lasted up to the Early Maastrichtian in the Outer Carpathians (Malata *et al.* 1996; Waśkowska *et al.* 2019), and numerous *Placentammina placenta*, *Caudammina ovulum* and *Caudammina excelsa* range from the Early Maastrichtian up to the Danian (e.g., Geroch 1960; Jurkiewicz 1967; Olszewska 1980; Beckmann *et al.* 1982; Hanzlíková 1983; Malata *et al.* 1996; Malata 2002; Bąk 2004; Waśkowska-Oliwa 2008; Waśkowska *et al.* 2018). Coupling the standard zonation based on the occurrence of index taxa with acmes results in a more detailed biostratigraphic scheme. The relatively long-term zones like the *Rzehakina inclusa* and *Rzehakina fissistomata* can be divided into shorter age intervals. In the *Rzehakina inclusa* Zone, the lower part is distinguished by the *Rzehakina inclusa–Caudammina gigantea* acme lasting up to the Early Maastrichtian and the upper part of the zone is distinguished by the *Rzehakina inclusa–Placentammina*/*Saccammina* and *Caudammina excelsa* assemblage which lasts up to the Cretaceous/Paleocene boundary. In the lower part of the Paleocene *Rzehakina fissistomata* Zone, a *Placentammina*/*Saccammina* and *Caudammina excelsa* assemblage can be distinguished.

CONCLUSIONS

The Jaworzynka Formation is the Upper Cretaceous to Paleocene lithostratigraphic unit of the Magura Nappe. The occurrence of biotite and feldspar rich sandstones is the most characteristic feature that distinguishes it from other formations of the same age in the Magura Nappe, i.e., the Szczawina Sandstone, Ropianka and Białe formations. This Formation is widespread in the marginal part of the Magura Nappe, called the Siary Zone, being best developed in the region between Jaworzynka and Koniaków in the Silesian Beskid Mts, where the most representative profiles are located. It continues eastward to the central part of the Polish Carpathians, and east of Dunajec River is completely replaced by the Ropianka Formation. Its equivalent named the Soláň Formation occurs in the Moravskoslezské Beskydy Mts in the Czech and Slovak Republics.

Although no continuous outcrop of the Formation is encountered in the mentioned region, its composite section has been constructed from several sections in the Jaworzynka village vicinity and surroundings. On the basis of field study and detailed micropalaeontological analysis of foraminiferal assemblages we include the entire sandstone-shale succession between the variegated shales of the Santonian–Campanian Cebula Shale Formation and the Paleocene Eocene Łabowa Shale Formation in the Jaworzynka Formation.

According to our study, the formation displays a complex structure in the stratotype area and can be subdivided to four lithological members:

Biotite Sandstone and Shale complex (I) predominated by very thick- to medium-bedded sandstones that also contain besides quartz numerous feldspars, glauconite grains and biotite. They are interlayered by thin-bedded shale or sandstone-shale packages. Within this complex, foraminifera representing the upper part of the *Caudammina gigantea* Zone and the lower part of the *Rzehakina inclusa* Zone are documented, corresponding to a Middle Campanian–earliest Maastrichtian age.

Shale complex (II) is composed mostly of dark grey, bluish and greenish muddy, non-calcareous shales, sparsely intercalated by thin-bedded sandstones. It contains a Maastrichtian assemblage of agglutinated foraminifera typical of the *Rzehakina inclusa* Zone.

Mutne Sandstone Member (III) is built mainly of thick- and very thick-bedded sandstones, and rarely contains conglomerates with fragments of metamorphic rocks, marls and limestones as their most distinct components. The sandstone packages are intercalated by thin layers of dark grey shales and laminated mudstones. The analysed foraminiferal assemblages from the shale intervals are characteristic for the Maastrichtian–Lower Paleocene (Danian) and are representative of the upper part of the *Rzehakina inclusa* Zone and lower part of the *Rzehakina fissistomata* Zone.

Thin-bedded Turbidite (IV) complex of a few m thickness consists of turbidites composed of grey and greenish-grey mudstones and very thin-up to medium-bedded grey, quarzitic sandstones. It contains foraminifera of Late Paleocene age representing the *Rzehakina fissistomata* Zone.

The stratigraphic range of the Jaworzynka Formation in the stratotype area, extending from the Middle Campanian up to the Late Danian, is also confirmed by the biostratigraphical analyses of the under- and overlying variegated shales.

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APPENDIX

Alphabetical list of foraminifera species mentioned in the paper:

Ammodiscus cretaceus (Reuss, 1946)
Ammodiscus pennyi Cushman and Jarvis, 1928
Ammodiscus peruvianus Berry, 1928
Ammodiscus planus Loeblich, 1946
Ammodiscus tenuissimus Grzybowski, 1898
Ammolagena clavata (Jones and Parker, 1860)
Ammosphaeroidina pseudopauciloculata (Mjatliuk, 1966)
Annectina biedai Gradstein and Kaminski, 1997
Annectina grzybowskii (Jurkiewicz, 1960)
Aschemocella carpathica (Neagu, 1964)
Aschemocella grandis (Grzybowski, 1898)
Caudammina excelsa (Dylążanka, 1923)
Caudammina gigantea (Geroch, 1960)
Caudammina ovuloides (Grzybowski, 1901)
Caudammina ovulum (Grzybowski, 1896)
Conglophragmium irregularis (White, 1928)
Cribrostomoides subglobosus (Cushman, 1910)
Dorothia indentata Cushman and Jarvis, 1928
Dorothia trochoides (d'Orbigny, 1852)
Eratidus gerochi Kaminski and Gradstein, 2005
Glomospira (*Agathamminoides*) *serpens* (Grzybowski, 1898)
Glomospira charoides (Jones and Parker, 1860)
Glomospira diffundens Cushman and Renz, 1946
Glomospira glomerata (Grzybowski, 1898)
Glomospira gordialis (Jones and Parker, 1860)
Glomospira irregularis (Grzybowski, 1898)
Haplophragmoides eggeri (Cushman, 1926)
Haplophragmoides horridus (Grzybowski, 1901)
Haplophragmoides kirki Wickenden, 1932
Haplophragmoides majtliukae Maslakova, 1955
Haplophragmoides walteri (Grzybowski, 1898)
Hormosina velascoensis (Cushman, 1926)
Hyperammina dilata Grzybowski, 1896
Hyperammina elongata Brady, 1878
Kalamopsis grzybowskii (Dylążanka, 1923)
Karrerulina coniformis (Grzybowski, 1898)
Karrerulina conversa (Grzybowski, 1901)
Karrerulina horrida (Myatlyuk, 1970)
Lituotuba lituiformis (Brady, 1979)
Nothia excelsa (Grzybowski, 1898)
Paratrochamminoides acervulatus (Grzybowski, 1896)
Paratrochamminoides contortus (Grzybowski, 1898)
Paratrochamminoides deflexiformis (Noth, 1912)
Paratrochamminoides dubius (Grzybowski, 1901)
Paratrochamminoides gorayskii (Grzybowski, 1989)
Paratrochamminoides heteromorphus (Grzybowski, 1898)
Paratrochamminoides mitratus (Grzybowski, 1901)
Paratrochamminoides multilobus (Dylążanka, 1923)
Paratrochamminoides olszewskii (Grzybowski, 1898)
Paratrochamminoides uviformis (Grzybowski, 1901)
Placentammina placenta (Grzybowski, 1989)
Psammosphonella cylindrica Glaessner, 1937
Remesella varians (Glaessner, 1937)
Reophax duplex Grzybowski, 1896
Reophax elongatus Grzybowski, 1898
Reophax guttifer (Brady, 1881)
Reophax nodulosus Brady, 1879
Reophax plana Halkyard, 1918
Reophax trinatinensis (Cushman and Renz, 1946)
Rhabdammina discreta Brady, 1881
Rhabdammina linearis Brady, 1879
Rhizammina indivisa Brady, 1884
Rzehakina epigona (Rzehak, 1895)
Rzehakina fissistomata (Grzybowski, 1901)
Rzehakina inclusa (Grzybowski, 1901)
Rzehakina lata Cushman and Jarvis, 1928
Rzehakina minima Cushman and Renz, 1946
Saccammina grzybowskii (Schubert, 1902)
Saccammina scabrosa Mjatliuk, 1970
Saccamminoides carpathicus Geroch, 1955
Spiroplectammina dentata (Alth, 1850)
Spiroplectammina spectabilis (Grzybowski, 1898)
Subrepohax pseudoscalaris (Samuel, 1977)
Subrepohax scalarias (Grzybowski, 1896)
Thalmannammina subturbinata (Grzybowski, 1898)
Trochammina bulloidiformis (Grzybowski, 1896)
Trochammina globigeriniformis (Jones and Parker, 1865)
Trochammina quadriloba (Grzybowski, 1896)
Trochammininopsis altiformis (Cushman, 1946)
Trochamminoides coronatus (Brady, 1879)
Trochamminoides flolius (Grzybowski, 1898)
Trochamminoides grzybowskii Kaminski and Geroch, 1992
Trochamminoides proteus (Karrer, 1966)
Trochamminoides subcoronatus (Grzybowski, 1896)
Trochamminoides variolarius (Grzybowski, 1898)