Annales Societatis Geologorum Poloniae (2016), vol. 86: 415–427. doi: https://doi.org/10.14241/asgp.2016.018

THE SOKOLISKA LIMESTONE, A NEW REGIONAL MARKER HORIZON OF COCCOLITH LAMINITES IN THE OLIGOCENE OF THE OUTER CARPATHIANS: DIAGNOSTIC FEATURES AND STRATIGRAPHIC POSITION

Agnieszka CIUREJ[1, 2] & Grzegorz HACZEWSKI[2]

[1] *Polish Academy of Sciences. Institute of Geological Sciences, Research Centre in Cracow, Senacka 1, 31-002 Kraków, Poland; e-mail: ndciurej@cyf-kr.edu.pl*
[2] *Institute of Geography, Pedagogical University of Cracow, Podchorążych 2, 30-084 Kraków, Poland; e-mail: sghaczew@interia.pl*

Ciurej, A. & Haczewski, G. 2016. The Sokoliska Limestone, a new regional marker horizon of coccolith laminites in the Oligocene of the Outer Carpathians: diagnostic features and stratigraphic position. *Annales Societatis Geologorum Poloniae*, 86: 415–427.

Abstract: Isochronous horizons of pelagic coccolith limestones are important regional stratigraphic markers in the Oligocene sequences of the Outer Carpathians. Three widely recognized limestone horizons are the Tylawa Limestones, the Jasło Limestone and the Zagórz Limestone horizons. Another regional marker horizon is described here, the Sokoliska Limestone horizon, situated between the Jasło Limestone and Zagórz Limestone horizons in the nannoplankton NP24 Zone. Its lithologic characteristics allow it to be distinguished from the other limestones, especially under the optical microscope. Its dark laminae are greatly enriched in non-calcareous material. The limestone contains tests of planktonic foraminifers, but these are much less abundant than in the Jasło Limestone. The boundaries with the marly shales above and below are often more gradational than is the case with the other limestone horizons. The Sokoliska Limestone has been recognized over a distance of ca. 550 km in the Skole (Tarcău) and Silesian units of the eastern and northern parts of the Outer Carpathians. Four sections of the Sokoliska Limestone horizon in the Polish and Romanian Carpathians are described; the exposure in the Sokoliska cliff of the Solinka River at Bukowiec was selected as the reference locality.

Key words: Coccolith limestone, Sokoliska Limestone, Oligocene, isochronous marker, Outer Carpathians.

Manuscript received 30 November 2015, accepted 15 November 2016

INTRODUCTION

Isochronous marker horizons are valuable tools in the stratigraphical analysis of sedimentary series that are poor in biostratigraphically useful fossils and have diachronous boundaries between lithosomes. This is the case for the Oligocene sedimentary series in the external part of the Outer Carpathian fold-and-thrust belt. The Oligocene sequence makes up about a half of the sediment column, even though its deposition lasted only 5.8 Ma of the 130 Ma, during which the entire sequence accumulated (e.g., Książkiewicz, 1972, 1975; Rögl, 1999; Golonka, 2000; Oszczypko, 2006). Intercalations of tuffs, cherts, diatomites and coccolith limestones have been used as regional stratigraphic markers within this sequence (e.g., Sikora *et al.*, 1959; Jucha, 1969; Ślączka, 1971; Kotlarczyk and Kaczmarska, 1987; Haczewski, 1989; Garecka, 2012). Coccolith limestones proved to be the best because of their widespread distribution over the entire area of the Outer Carpathians, easy identification in the field, limitation to very short time intervals (on the order of 1 ka) and the correlation of annual or circannual laminae. The correlation allowed for identification of such events as ancient earthquakes (Haczewski, 1996) or turbidity currents (Haczewski, 1981), with a precision of one year over tens or even hundreds of kilometres.

Three marker horizons of coccolith limestones have been widely used as regional markers in the Oligocene of the Outer Carpathians: the Tylawa Limestones (with two subhorizons), the Jasło Limestone and the Zagórz Limestone. Uhlig (1888) was the first to note that the same distinctive fish-bearing fissile limestone occurs in the different facies of various areas, but he did not venture into a discussion on which are isochronous: limestones or facies boundaries. In the course of further detailed geological surveys, it became apparent that the limestone horizons are isochronous and the major lithological units of the Oligocene sequence are strongly diachronous (Shakin, 1958; Jucha and Kotlarczyk, 1961; Koszarski and Żytko, 1961). The term

Jasło Shales – an imprecise translation of Uhlig's Jasloer Kalkschiefer or Kalkschiefer von Jasło – has been used for decades to describe these limestones until the oldest horizon was distinguished as the Tylawa Limestone by Jucha (1969). Haczewski (1989) proposed giving a separate name to each convincingly identified limestone horizon, in order of decreasing age: the Tylawa Limestones (plural, because of the presence of separate subhorizons), the Jasło Limestone and the Zagórz Limestone. He also presented the distinctive lithological characteristics of the three horizons that can be used to distinguish the limestones from one another. The limestones are pelagic in origin (Koszarski and Żytko, 1961; Jucha, 1969; Haczewski, 1989) and each limestone horizon represents a period of intense deposition of coccolith mud as a result of massive blooms of coccolithophores. These events of coccolith mud deposition each lasted several hundred years and were punctuated with events of instantaneous deposition of clastic material by gravity flows. As a result, each episode of coccolith mud deposition is represented by a sequence of clastic beds with the limestone layers often preserved incompletely, usually as subordinate intercalations. At a few localities the limestones are not interrupted in vertical sequence and are preserved as a single thicker limestone layer (see Haczewski, 1989, for more details). The present authors define each "limestone horizon" as the part of the rock sequence between the base of the lowermost layer and the top of the uppermost layer of a given type of coccolith limestone.

Many occurrences of pelagic limestones within the Oligocene sequence were not assigned to any of these three horizons for various reasons. Some are preserved only as millimetres-thick limestone laminae, so that their distinctive lithologic characteristics are not seen. Others lack the characteristics of pelagic sediment; they are redeposited lime muds, largely composed of coccolith debris. This is the case especially for the so-called "Dynów Marl" – limestones that form bundles up to ca. 30 m thick in the lower part of the Oligocene sequence, below the Tylawa Limestones, usually close to the so-called Menilite Chert. Some layers of coccolith limestones have been recognized only in a few outcrops over a limited area (e.g., the Wujskie Limestone of Kotlarczyk *et al*., 2006, or Coccolithic Limestone 3 of Melinte-Dobrinescu and Brustur, 2008). Some other occurrences may be the equivalents of any of the three horizons named above, but they depart from the diagnostic criteria. This may have been caused by locally different conditions of deposition (e.g., the Folusz Limestone of Haczewski, 1989). Some layers of coccolith limestones have been found in sections with one or two of the three named horizons present, but obviously beyond their area of occurrence. They have never been confirmed in other areas and are considered to be local in occurrence. This is the case for the thin limestone layers situated some 40 m above the Zagórz Limestone in the Vinețișu section, in Romania (Wdowiarz, 1959; Haczewski, 1989).

None or the situations listed above applies to the horizon of the "Middle Jasło Shale" of Koszarski and Żytko (1961). These authors described a thin limestone horizon between the Jasło Limestone (their Lower Jasło Shales) and the Zagórz Limestone (their Upper Jasło Shales). They found it in many outcrops in various facies zones of the Oligocene sequence and considered it to be a separate marker horizon, potentially of regional significance. In spite of the wide use of the Jasło and Zagórz limestones in regional studies (Grasu *et al*., 1982; Alexandrescu and Brustur, 1985; Ionesi, 1986; Brustur and Alexandrescu, 1989; Ştefănescu *et al*., 1993; Rusu *et al*., 1996; Melinte-Dobrinescu and Brustur, 2008) and on serial geological maps in Poland and Romania, the middle horizon has escaped closer attention.

In the course of recent field work, the present authors studied several well exposed sections of the limestone horizon discussed, some of them in continuity with one or both of the neighbouring horizons. Below the authors present a detailed description of this marker horizon in four well exposed, geographically and tectonically separated localities. The authors define its diagnostic features and propose the name Sokoliska Limestone for it.

REGIONAL SETTING

The Oligocene sequences in the Outer Carpathians are up to ca. 2.5 km thick. The most distinctive for the lower part of the sequence are dark, organic-rich shales, known as the Menilite Shales in Poland, Ukraine, Slovakia and Czech Republic, and as the Dysodilic Shales in Romania. They usually have intercalations of chert and redeposited coccolith limestones (the so-called Dynów Marl; see above) near their base. They are overlain with siliciclastic gravity mass-flow deposits. The massive, poorly cemented, white or greenish, often very thick-bedded, Kliva Sandstones are the typical Oligocene facies in the external part of the Carpathian arc, in the Skole (Skyba in Ukraine, Tarcău in Romania) Nappe. Rhythmical turbiditic sequences of sandy, normal or shaly flysch with calcareous sandstones prevail in the Oligocene sequence in the central and inner part of the arc. They are included in the Krosno Beds in Poland and Ukraine and in their equivalents, the Pucioasa Beds (rhythmic turbidites) and the Fusaru Beds (massive sandstones) in Romania. This simplified description of the Oligocene lithofacies in the Outer Carpathians includes only the major ones and those present in the sections described. The Jasło and Zagórz limestone horizons are present in the Menilite Shale in the external zone of the Outer Carpathians and they gradually shift up the section across the tectonic units, up to the upper part of the Krosno Beds in the inner zone of the arc. The stratigraphic subdivision and correlation of the Oligocene sequence is hampered by the strong diachronism of the major lithofacies and by the paucity of fossils, many of which are endemic to the Paratethys. These characteristics reflect the progressive migration of depositional centres across the land-locked Paratethys basin. Thus isochronous marker horizons are essential for the regional correlation of the Oligocene series laid down in the Outer Carpathian part of the Paratethys.

METHODS

The sections with the limestone horizon studied were logged in the field with a precision of 1 mm. Oriented (with respect to top and bottom) samples were taken from the complete thickness of all limestone layers within the horizon and from the directly adjacent host strata. The limestone samples were cut perpendicular to the stratification and photographed in conditions of uniform lighting. The photographs from each locality were digitally assembled into uniformly scaled, continuous sequences of the limestone.

Mesoscopic lithological description of the limestones was carried out from the bottom to the top of each section on cut and polished surfaces of the limestone layers. Microscopic examination was done on standard uncovered petrographic thin sections 3 × 2 cm, cut perpendicular to lamination and diagonally, at an angle of 50° to the lamination in order to better separate various levels within the laminae. The thin sections were studied with the Zeiss Axioskop 50 (transmitted light) polarizing microscope, equipped with a digital camera (Canon Power Shot A640), and using a scanning electron microscope (SEM): FEI Nova NanoSEM 200, at low vacuum, and voltage 15 to 20 kV on non-coated samples. The samples were studied using various modes of observation: charge contrast imaging (CCI) and back-scattered electrons (BSE). The SEM-BSE mode allowed the authors to study the chemical composition of components. The SEM-CCI mode allowed study of the anatomical details of calcareous nannofossils in strongly cemented samples that had been regarded as barren of nannoplankton after the standard separation treatment for calcareous nannofossils. More technical details are given in Ciurej (2010).

Calcareous nannoplankton from four samples in each section was analysed in smear slides under a Nikon optical microscope, using 1000× magnification.

The samples are stored at the Institute of Geological Sciences, Kraków Resarch Centre of the Polish Academy of Sciences.

THE STUDIED SECTIONS

Bukowiec

The section is situated in the eastern part of the Polish Outer Carpathians (Fig. 1), in the central part of the transverse section of the Silesian Unit. The expression "Unit" is a long-established term used in the regional literature on the Outer Carpathians for major nappes, distinguished by a combination of tectonic and facies criteria, so that their boundaries in some places do not follow the major thrust surfaces. The outcrop in Bukowiec village lies in the left steep bank of the Solinka River, 30 km to the SE of Sanok (Fig. 1B, D) at 49°18′32″N, 22°24′40″E (WGS 84). The Jasło and Zagórz horizons are present here, but a fault disrupts the section between the Sokoliska and the Zagórz horizons. The presence of the Jasło Limestone at Bukowiec was shown on a geological map by Wdowiarz (1980). The limestone layers at this locality that the present authors now separate as the Sokoliska Limestone horizon, were described by Haczewski (in Leszczyński *et al*., 1986) as the highest part of the Jasło Limestone horizon. The Sokoliska Limestone horizon is here 2 m thick and includes 7 limestone layers with a total thickness of 9.1 cm (Fig. 2). The lowermost layer is located 5.5 m above the top of the Jasło Limestone. The layers are from less than 1 cm to 2.5 cm thick. The weathered thin limestone layers are hard to distinguish visually among the host clastics; only the thickest layers are clearly distinct (Figs 2, 3). All the limestone layers display submillimetric to millimetric lamination, consisting of alternations of light and dark laminae, though at some levels the mesoscopic visibility of laminae is obscured on weathered surfaces.

The lowest layer, 2 cm thick (BUK-S1; Fig. 2), is light, distinctly laminated, with the thick light laminae predominant. However, there are some bundles of thin, light laminae, alternating with predominant thicker dark laminae.

The next higher layer is the thickest one (2.5 cm; BUK-S2; Fig. 2). It is slightly darker and the laminae are somewhat less distinct, with predominance of thick, continuous, dark laminae and common, discontinuous, lenticular, light laminae. The limestone passes gradually upwards to pelletal marly claystone.

The three higher layers are lighter and more distinctly laminated (BUK-S3–BUK-S5; Fig. 2). A lamina of marly mudstone is present among the bundles of limestone laminae. The lowest limestone layer is overlain with a sharp boundary by fine-grained sandstone, whereas the two higher layers are intercalated with shales.

The two highest layers (BUK-S6 and BUK-S7) are darker and they consist of a bundle of thin laminae, with the dark component predominating. These layers are readily discernible among the host light grey, marly mudstones.

The intervening clastic layers between the limestones vary within the section (Figs 2, 3). Shales are either marly, grey or rarely dark brown or dark to black and non-calcareous. There are also sporadic thin layers of grey, micaceous, calcareous sandstones, very fine-grained and fine-grained, less frequently medium-grained. The sandstone layers display horizontal, wavy, and cross lamination, rarely convoluted lamination, corresponding to the $T_{c–d}$ Bouma divisions. Light-grey, mostly calcareous mudstones are also present. Some mudstones in direct contact with the limestone layers contain dispersed, calcareous pellets (see mudstone in BUK-S2 and BUK-S6).

The authors propose this site as the reference section for the horizon of "the middle Jasło Shales" of Koszarski and Żytko (1961) and suggest the name Sokoliska Limestone horizon for it, wherever it can be recognized with confidence. The name Sokoliska had been used for the 30 m high cliff in the left bank of the San River by ancient inhabitants of the village of Bukowiec and it fell into disuse after World War II. A toponomastic map (Krukar, 2014), based on interviews with the resettled inhabitants, restored this name. The authors have chosen not to use the name of the village of Bukowiec to avoid confusion with the exotic Eocene limestones from another location named Bukowiec, a now abandoned village on the Halicz Stream, 34 km to SE from the locality described here. The Jasło, Sokoliska and Zagórz limestone horizons are exposed there too (Haczewski, 1989), but the Sokoliska Limestone is greatly reduced there.

Tyrawa Solna

This site lies in the eastern part of the Polish Carpathians, ca. 15 km NW of Sanok (Fig. 1), in one of the inner-

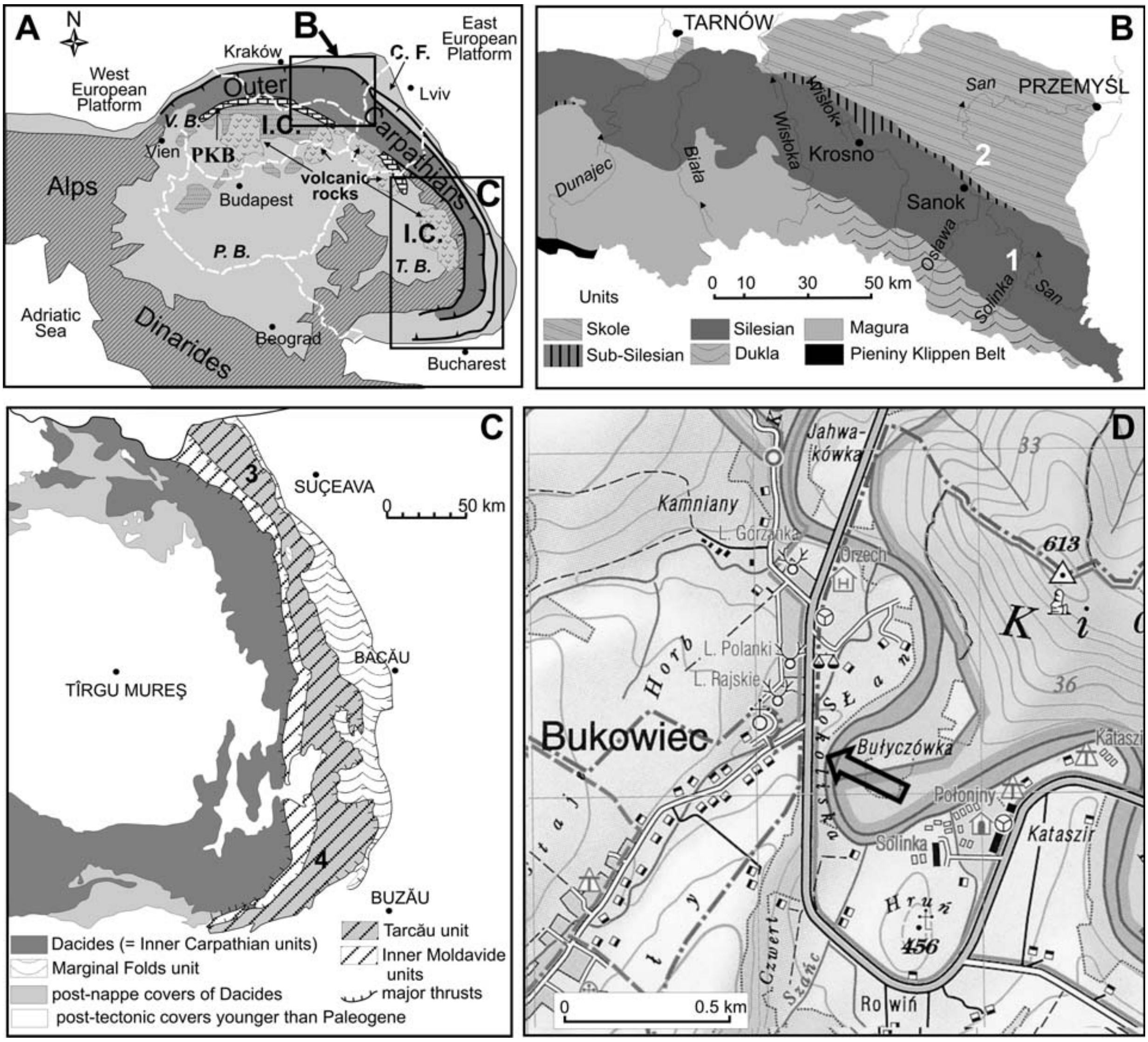

Fig. 1. Location of study area. **A.** Simplified geological map of the Outer Carpathians with the location of study area (based on Kovač *et al.,* 1998); C.F. – Carpathian Foredeep, I.C. – Inner Carpathians, P.B. – Panonian Basin, PKB – Pieniny Klippen Belt, T.B. – Transylvanian Basin, V.B. – Vienna Basin. **B.** Simplified geological map of the Polish part of the Outer Carpathians (after Książkiewicz, 1972). **C.** Simplified geological map of the Romanian part of the Outer Carpathians. Location of the studied sections with the Sokoliska Limestone: 1 – Bukowiec; 2 – Tyrawa Solna; 3 – Ascuns; 4 – Teherău. **D.** Detailed location map of exposure in the Sokoliska cliff at Bukowiec on the Solinka river, indicated as the reference locality (map by Krukar, 2014).

most tectonic slices of the Skole Nappe. The exposure lies in the steep right bank of the San River, at the base of the precipitous NW slope of Pierdziesz Hill, west of the village of Tyrawa Solna. The sharp crest of Pierdziesz is made up of a resistant package of the Kliva Sandstone, the predominant component of the Menilite Beds in this area. The San valley here cuts across the geological structures transversally with respect to the structural grain. The geographical coordinates of the exposure are N49°36′46″, E22°16′10″ (WGS 84). The sequence of the three horizons of the "Jasło Shales" in this outcrop was described by Koszarski and Żytko (1961). They and later authors referred to this site as Mrzygłód. However, the town of Mrzygłód is located on the other side of the San, and so the present authors use the name of the village where the outcrop occurs, Tyrawa Solna. Koszarski and Żytko (1961) noted that the Menilite Shale between the lower and upper Jasło Shales includes a few thin layers of laminated and non-laminated Jasło Limestone, representing the middle horizon.

The authors logged 8.9 cm of coccolith limestones in six layers, 0.5 to 2.6 cm thick, within the 2.4-m-thick section of the Sokoliska Limestone horizon at this locality (Fig. 2). The lowest layer lies 2.5 m above the top of the Jasło Limestone. All layers display characteristic submillimetric to millimetric lamination, consisting of alternations of light and dark, laminae similar to those at the Bukowiec section.

The lowest layer, 2 cm thick (MRZ-S4, Fig. 2), is dark owing to the predominance of thick dark laminae alternating with faint, often lenticular, light laminae. This layer is barely distinguishable from the host sediment, which is dark, slightly calcareous shale.

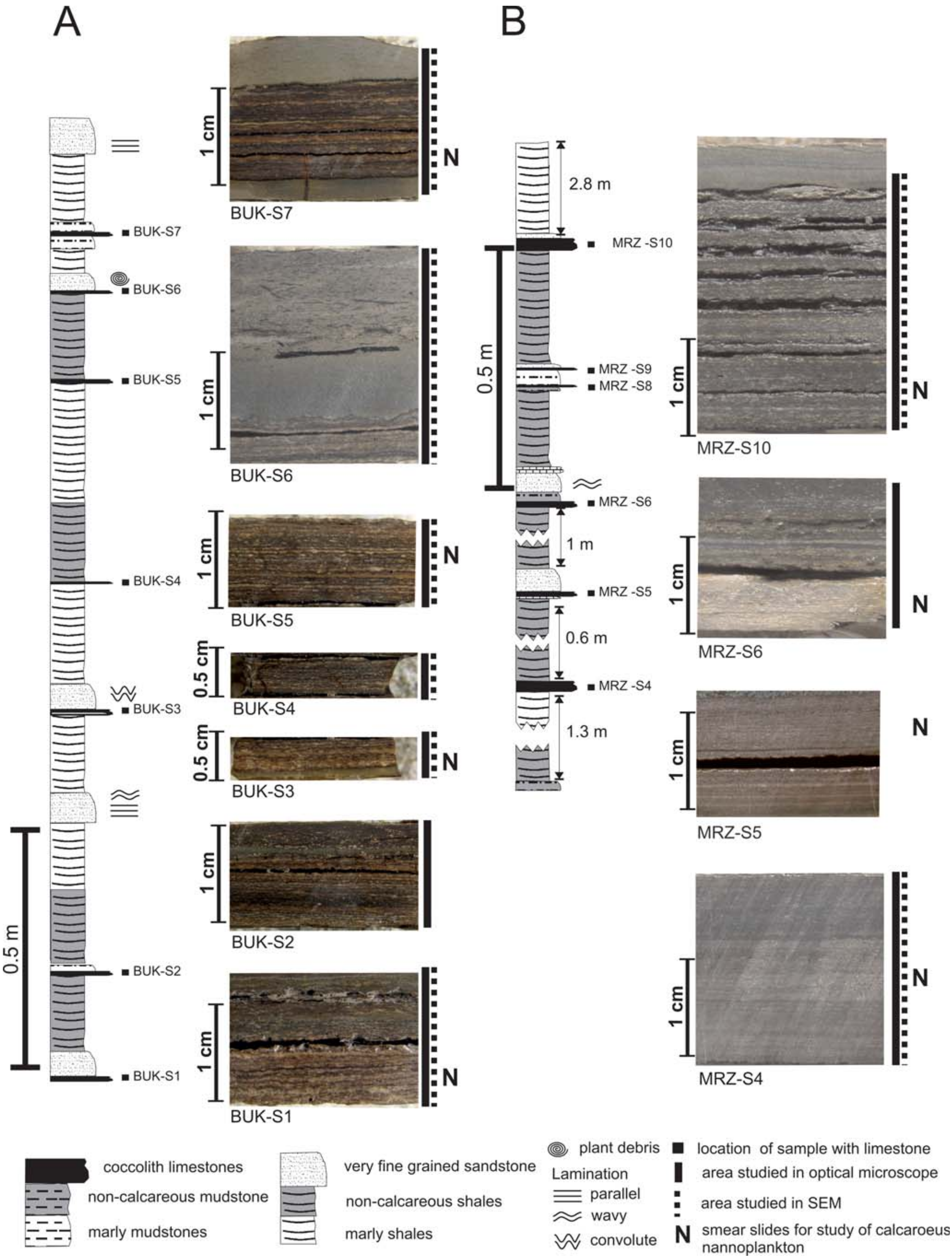

Fig. 2. Lithological log with position of Sokoliska Limestone and composite photographic column from sections. **A.** Bukowiec, as in 2012. **B.** Tyrawa Solna, as in 2013. The photographs do not show full thickness of the layers, see text for thickness.

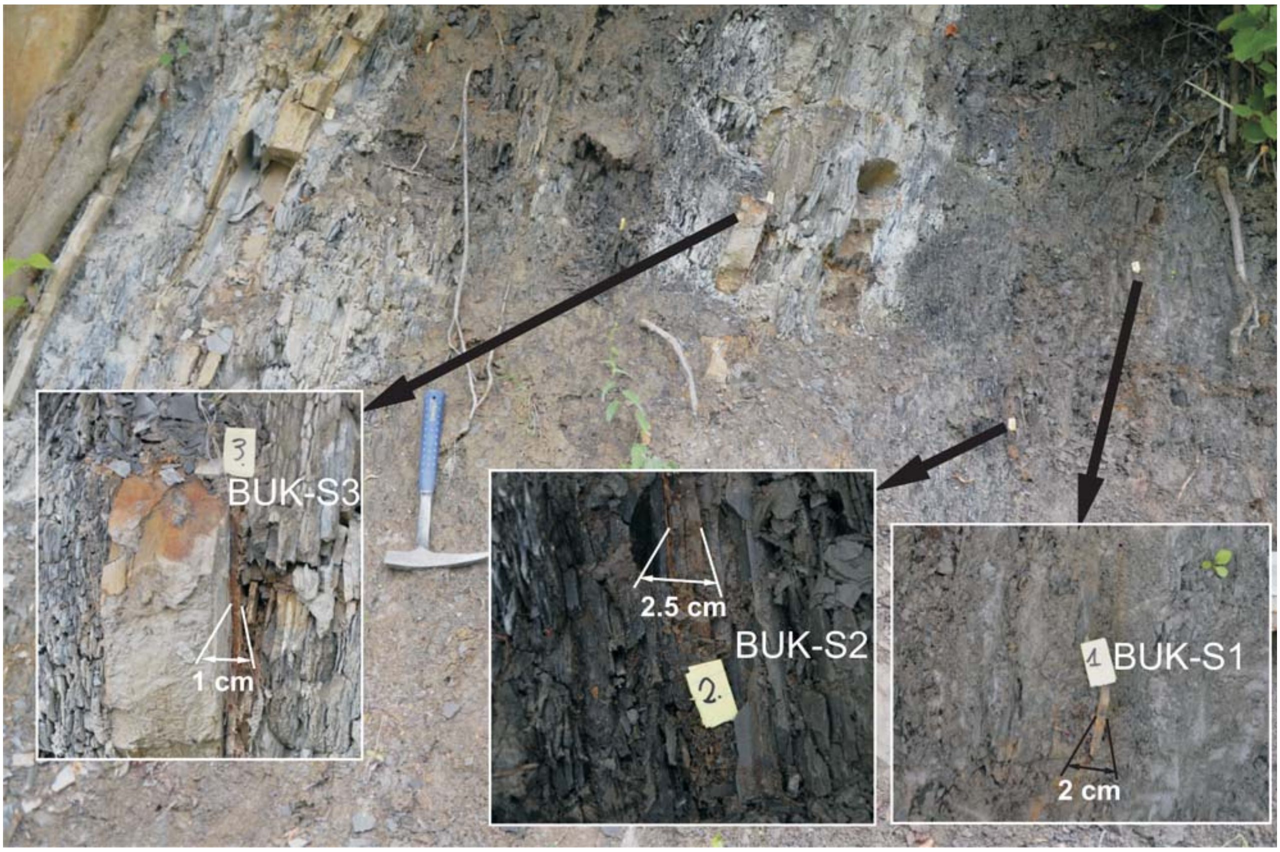

Fig. 3. Field view of the Sokoliska Limestone at Bukowiec, with the position of some samples; photo taken [in 2012].

The next layer, 1.2 cm thick, is lighter in colour, with thick, distinct, light laminae predominating (MRZ-S5, Fig. 2). The higher three layers (MRZ-S6, MRZ-S8, MRZ-S9), also light in colour, are composed of thin, rather continuous, dark and light laminae. Laminae of marly mudstone are present among the bundles of limestone laminae in each layer. The layer MRZ-S6 (Fig. 2) passes gradually upwards into pelletal marly claystone.

The uppermost layer (MRZ-S10, Fig. 2), 2.6 cm thick, is dark and consists of thick dark laminae and thin light laminae, partly lenticular.

The host sediments are similar to those in the Bukowiec section, although black, non-calcareous shales predominate in the Tyrawa Solna section.

Ascuns

This section is located in the northern part of the Romanian Outer Carpathians, in the inner part of the Tarcău Unit, which is a continuation of the Skole Unit of the Polish Carpathians. Four horizons of the coccolith limestones are exposed along the Ascuns Stream, a left (east) tributary of the Moldovița River joining it at the village of Moldovița. The exposure with the Jasło, Sokoliska and Zagórz limestone horizons (Fig. 1) is at 47°42′07.3″N, 25°33′38.3″E (WGS 84), ca. 1860 m on a straight line from where the streams cross the main street of the village. The Tylawa Limestone is exposed in the bed and banks of the same stream ca. 365 m to the SW (downstream) of this site. The location of the Tylawa and Jasło limestones and a stratigraphic column for this section are shown on the Sucevița Sheet of the detailed geological map of Romania (Joja *et al*., 1984).

The Sokoliska Limestone horizon starts ca. 3.7 m above the top of the Jasło Limestone. The section, 0.85 m thick, comprises four limestone layers with a total thickness of 5.7 cm and a maximum thickness of 2.2 cm.

Lamination in the limestones is similar to that in the Bukowiec section. The two lowest layers are darker, with the thick, dark laminae predominating. The light laminae have lenticular appearance (Fig. 5A). The upper two layers are lighter in colour, with distinct lamination and with predominance of thick, light laminae.

The host sediments are dark brown to black, non-calcareous shales with thin intercalations of mudstones and thin-bedded very fine-grained sandstones.

Teherău

The Teherău section is located in the southern part of the Romanian East Carpathians, in the middle part of the transverse section of the Tarcău Unit, ca. 60 km NW of the town of Buzău, in the Buzău River valley (Fig. 1). The section is exposed in a road cut on the eastern shore of the Siriu Dam lake, south of the outlet of the Teherău Stream valley, at 45°30′27″N, 26°13′43″E (WGS 84). The section has been described by Brustur and Alexandrescu (1989) and Rusu *et al*. (1996) as belonging to the Pucioasa Formation with the Fusaru Sandstone. A package of a few tens of metres of thin-

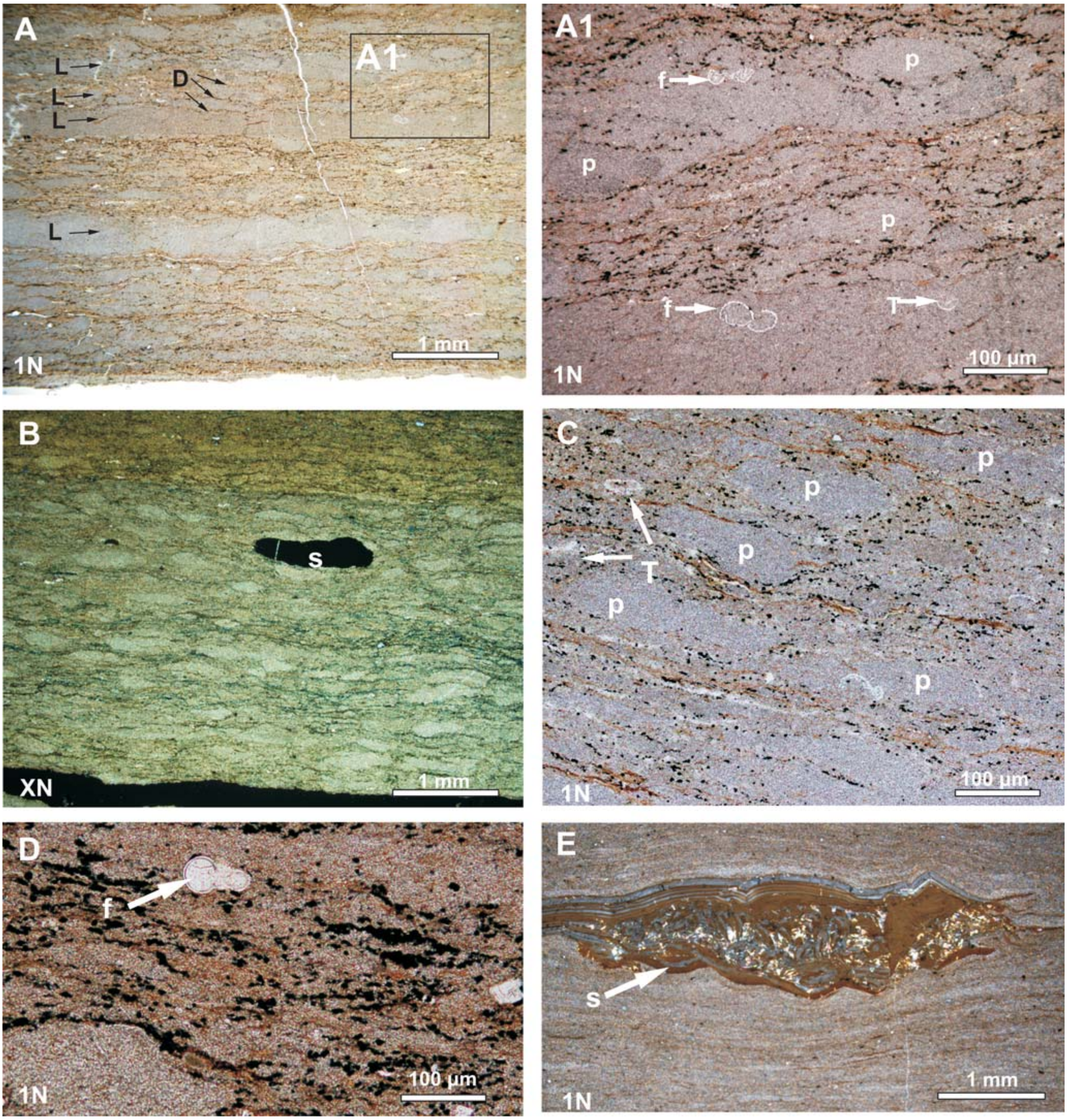

Fig. 4. Thin sections of Sokoliska Limestone from the Polish part of the Outer Carpathians. **A–C.** The thick light laminae (L) composed of coccolithophores (Fig. 6) are separated by thinner dark laminae (D), composed of detrital material (Fig. 8). The laminae are more or less laterally continuous with varying thickness, and have undulate boundaries. Pelletal structures (p), composed of coccolithophores, are present in all light laminae. Their shape and size varies within individual laminae. Calcareous resting spores (T) are common in the light and rare in the dark laminae. Rare tests of planktonic foraminifera (f) and common fish skeletons (s) are present. **D.** Details of tests of planktonic foraminifera (f). **E.** Details of fish skeletal remnants (s). Optical microscope: 1N – plane polarized light, XN – crossed polars. A – Bukowiec (BUK-S5); B–E – Tyrawa Solna (B, C – MRZ-S10; D, E – MRZ-S4). For sample location see Fig. 2.

bedded flysch is present within a huge sequence of thick-bedded Fusaru Sandstone. The Jasło Limestone is readily distinguished within this thin-bedded package and the Sokoliska Limestone starts 2.8 m above the top of the Jasło Limestone, just below the massive beds of the Fusaru Sandstone.

The Sokoliska Limestone horizon is 0.5 m thick here and consists of three layers of laminated limestone, 1.4, 1.8 and 1.2 cm thick, embedded in weathered, grey, fissile fine sandstone/mudstone. The limestones display submillimetric to millimetric lamination, consisting of alternations of light and dark laminae, similar to those in the Bukowiec section. The limestone layers are light in colour and the lamination is clearly visible. Laminae of marly mudstone are present among the bundles of limestone laminae (Fig. 5D).

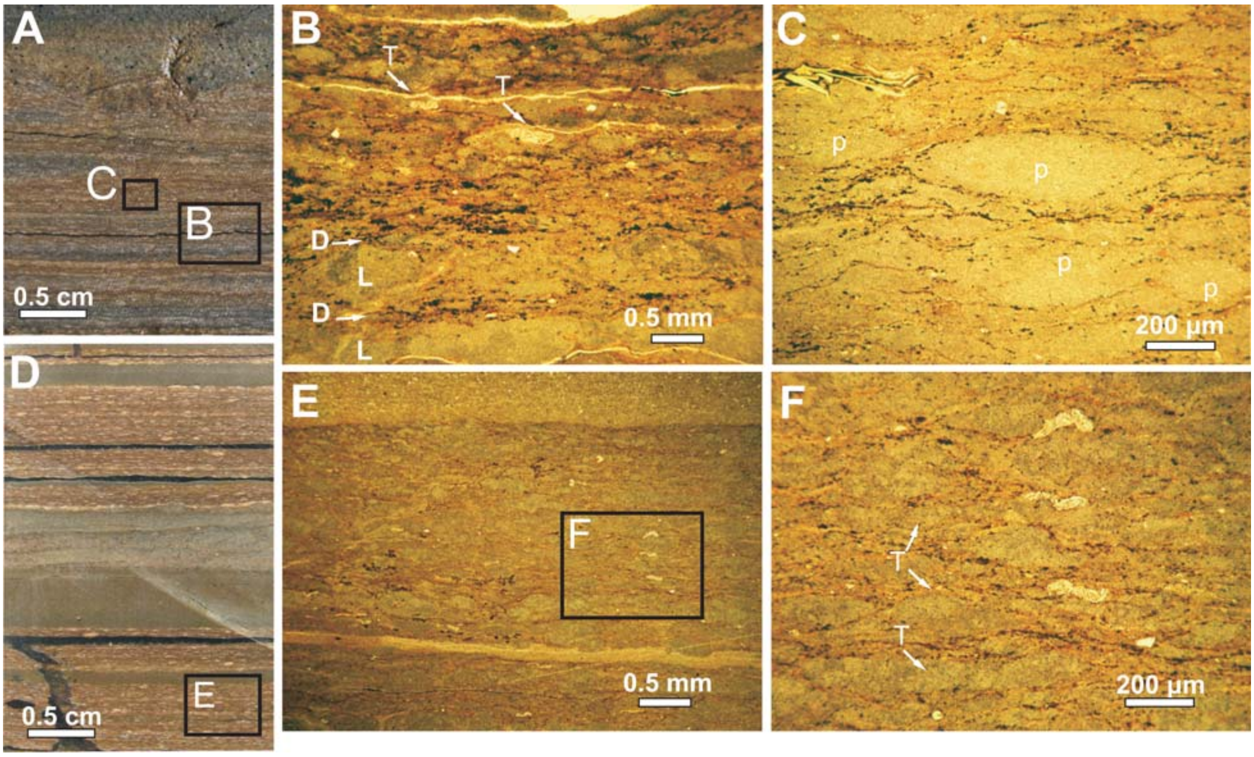

Fig. 5. Macroscopic views and thin sections of Sokoliska Limestone from the Romanian part of the Carpathians. **A–C.** Gradual enlargement of limestone from Ascuns (ASC -2); **D–F.** Gradual enlargement of limestone from Teherău (TEH-30A). The thick light laminae (L), composed of coccolithophores (Fig. 6) are separated by thinner dark laminae (D), composed of detrital material (Fig. 8). The laminae are more or less laterally continuous with undulate boundaries and variable thickness. The pelletal structures (p) within light laminae, calcareous preservative cysts (T), are also observed. Compare with Figure 4. A, D – macroscopic view; B, C, E, F – optical microscope, plane polarized light.

MICROSCOPIC CHARACTERISTICS OF THE SOKOLISKA LIMESTONE

Thin sections observed under the optical microscope confirm that the limestones studied consist of alternating light and dark laminae. Both types of laminae vary in thickness and lateral continuity. Some laminae are well defined and persistent in their thickness. Other laminae have more or less undulating boundaries, resulting in oscillating thickness (Figs 4, 5). The light laminae, usually between 20 and 300 µm, exceptionally up to 600 µm thick, show characteristic, micronodular structure due to the presence of pellets (see Haczewski, 1989). The pellets are arranged in horizontal laminae, they have sharp boundaries and are oval, lenticular or circular in cross-section. Their size varies from 30 to 300 µm, in some cases even up to 1000 µm. Individual laminae include pellets of various sizes. The structure of the light laminae is similar to that in the Jasło Limestone (see Haczewski, 1989). The pellets consist mainly of coccolithophore skeletons, represented by a low-diversity assemblage, dominated by *Cyclicargolithus floridanus* (Roth & Hay) Bukry. Other forms, such as *Coccolithus pelagicus* (Wallich) Schiller, *Dictyoccocites bisectus* (Hay, Mohler et Wade) Bukry et Percival, *Cyclicargolithus abisectus* (Müller) Wise are also present (Figs 6, 7; see also Garecka, 2012). The preservation of the coccoliths, as seen in thin sections under SEM, is very good to good and intact coccospheres are very common. There is little indication of dissolution, secondary overgrowth or mechanical fragmentation by compaction.

The scarce matrix in the light laminae consists of clay minerals, carbonate grains, pyrite and organic matter. It is present within the pellets and between them. These grains are usually smaller than 100 µm.

The dark laminae are usually 3 to 100 µm thick, exceptionally up to 600 µm (Figs 4, 5). The most common components are clay minerals (mainly kaolinite and illite), quartz, and feldspar. Their grains range in size from 1 to 15 µm, rarely exceeding 50 µm. Other components include: pyrite framboids, carbonate grains (calcite, ankerite, siderite, and dolomite), phosphatic debris (most likely fragments of fish skeletons), and organic matter (amorphous and fibrous) (Fig. 8).

Quite common in the limestones studied are spherical to ellipsoidal calcareous forms with walls constructed of prismatic elements. They are 50 to 100 µm in size, sometimes larger. Most are completely or partly collapsed, but the characteristic prismatic walls are still recognizable (Figs 4, 5, 9). These forms probably represent calcareous nannoplankton belonging to the group Thoracospahaeraceae Schiller (1930; see also Perch-Nielsen, 1985). Some of these forms are referable to calcareous dinoflagellates (Fütterer, 1976, 1977; Jafar, 1979; Tangen *et al.*, 1982). On the basis of the literature data (Fütterer, 1977; Jafar, 1979), the present authors interpret these forms as calcareous dinoflagellates or dinocysts, the resting stages of dinoflagellates.

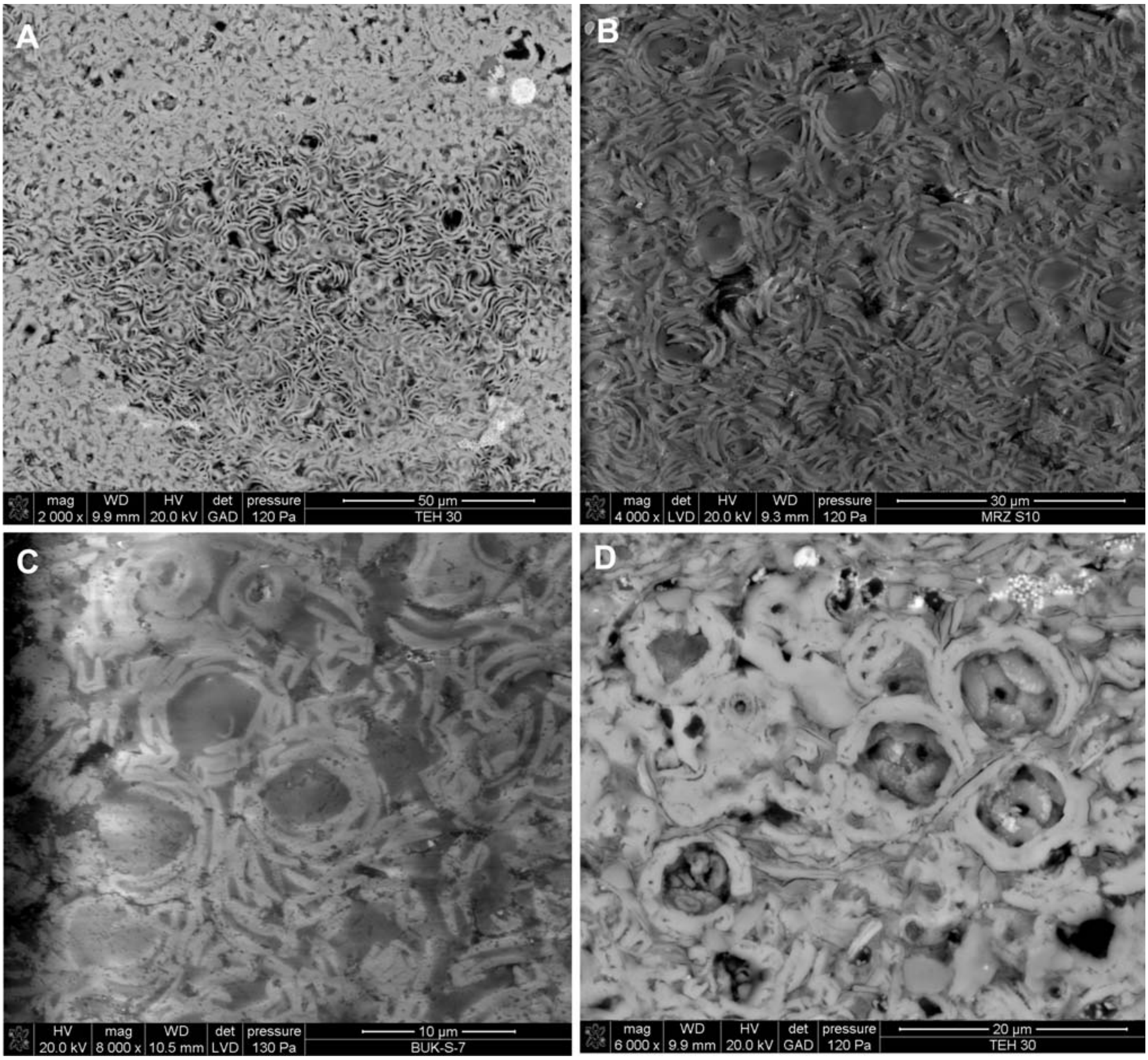

Fig. 6. SEM images from thin sections of the Sokoliska Limestone, showing coccolithophore remains in the light laminae. **A, B.** Association of intact well preserved coccospheres and loose coccolith plates, packed within pellets. Material is dominated *by Cyclicargolithus floridanus* (Roth & Hay); **C, D.** Details of cross section of intact coccospheres and loose coccolith plates of *Cyclicargolithus floridanus* (Roth & Hay). Note the lack or little indication of dissolution, secondary overgrowth or mechanical fragmentation by compaction on all images. Samples from sections: A, D – Teherău (TEH-30A); B – Tyrawa Solna (MRZ-S10), C – Bukowiec (BUK-S7).

Planktonic foraminifers were seldom observed in the limestones studied (Fig. 4D). These are small, usually poorly preserved forms. Fine bone debris is quite frequent, as are complete fish skeletons and lenses packed with phosphatic debris, apparently fish coprolites (Fig. 4B, E). They are as small as the typical components of the laminae, rarely larger.

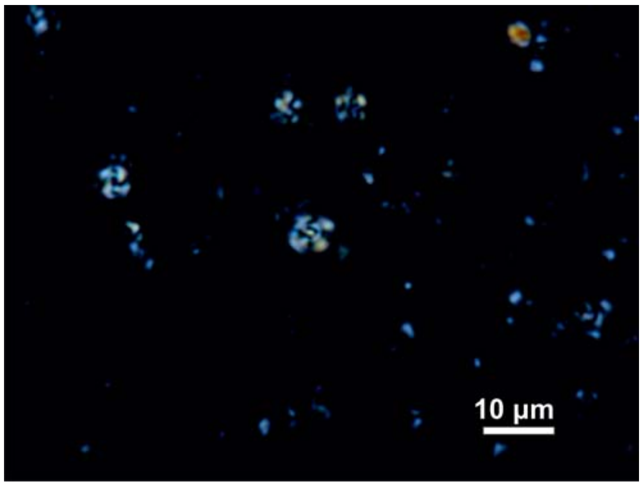

Fig. 7. Optical microscope view of coccolithophore assemblage in Sokoliska Limestone. The coccolithophore assemblage dominated by *Cyclicargolithus floridanus* (Roth & Hay) Bukry. Smear slide, crossed polars. Bukowiec (BUK-S7).

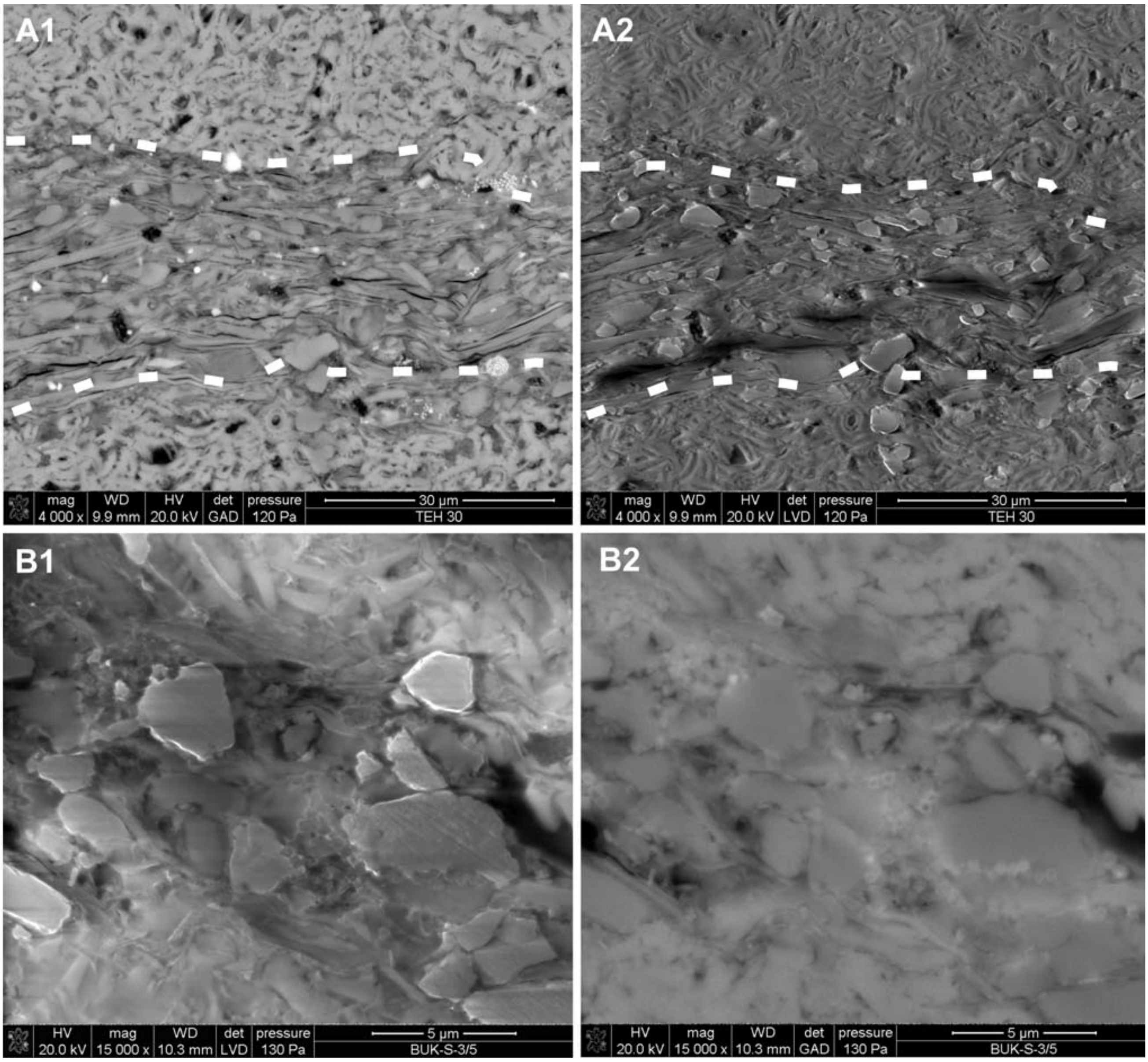

Fig. 8. SEM images from thin sections of the Sokoliska Limestone, showing components within dark laminae. **A1, A2.** The same field in BSE (A1) and CCI (A2) mode, with various amounts of detrital material (clay minerals, quartz, feldspars), pyrite, carbonate grains and organic matter; note the differences in size of detrital material; **B1, B2.** The same field in BSE (B1) and CCI (B2) mode, showing the predominance of quartz and clay minerals. A – Teherău (TEH-30A); B – Bukowiec (BUK-S3).

STRATIGRAPHIC POSITION

As assessed at Tyrawa Solna and at Bukowiec along the Halicz Stream, the position of the Sokoliska Limestone in the section between the Jasło Limestone and the Zagórz Limestone is below the middle, at 0.4 of the vertical distance between the two horizons (Tab. 1). The thicknesses of the limestone horizons and vertical distances between them depend on the host lithofacies. In a sequence of black shales, the vertical distance between the Jasło and Zagórz horizons is reduced to 6–10 m (Koszarski and Żytko, 1961; Haczewski, 1989), with the Jasło Limestone limited to a couple of closely lying thicker layers or even to one limestone layer (Haczewski, 1989). When the Jasło and Zagórz limestone horizons are present in a sequence of sandstone turbidites, alternating with redeposited, black, calcareous mudstones (Koszarski and Żytko, 1961; Haczewski, 1989; Bukowiec on the Halicz stream), they are separated by up to 150 m of the clastic sequence. This means that the sequence accumulated at different rates in different zones of the basin. If it is assumed that those rates remained roughly constant within each zone and that the Jasło Limestone accumulated in ca. 1000 years (750–1000 years according to Haczewski, 1989), then the whole time interval during which the Jasło, Sokoliska and Zagórz limestones were laid down lasted a few tens of thousands of years.

The biostratigraphical position of the Jasło and Zagórz limestone horizons, according to most authors falls within the nannoplankton NP24 Zone (Krhovský, 1981; Bąk, 2005; Melinte, 2005; Švábenická, *et al*., 2007). Bąk (1999) stud-

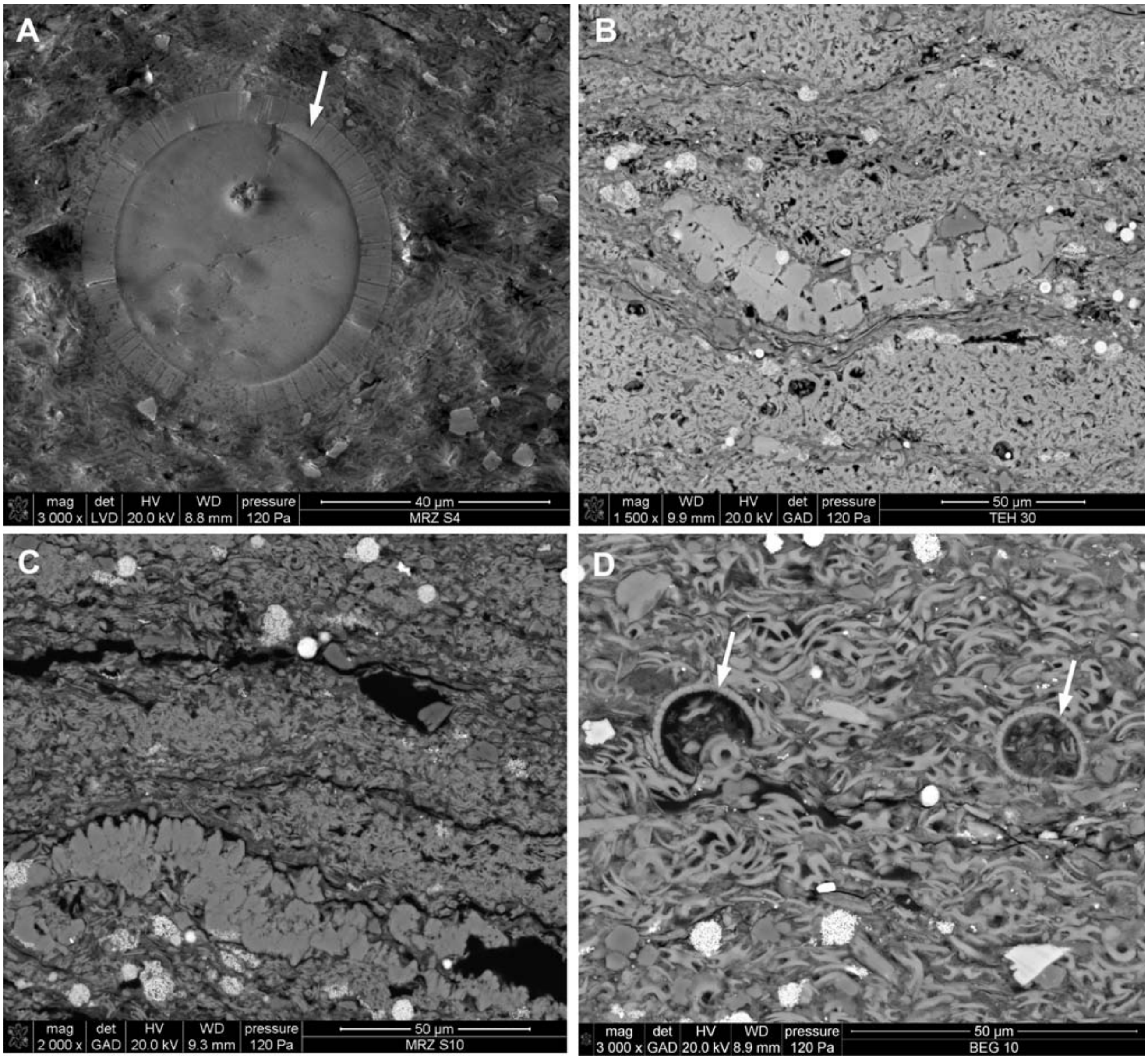

Fig. 9. SEM images from thin sections of the Sokoliska Limestone, showing calcareous nannofossils interpreted as calcareous dinoflagellates. **A.** Circular cross section of a well preserved test with wall (arrow) built of prismatic elements; **B, C.** Highly deformed test where the wall became totally collapsed and squeezed along the lamination. Note the characteristic prismatic wall in all deformed forms; **D.** Circular cross section of a test with wall (arrows) built of prismatic elements, partially deformed; note similarities with Figs. B and C in the wall structure.. A – CCI, B–D – BSE images. Samples from sections: A, C – Tyrawa Solna (MRZ-S4 and MRZ-S10, respectively); B – Teherău (TEH-30A); D – Bereźnica/Górzanka (BEG 10, loose specimen, location not studied in this paper).

Table 1

List of selected parameters of the Sokoliska Limestone from the sections studied

Location	Tectono-stratigraphic unit	Thickness of the Sokoliska Limestone horizon [m]	Summaries thickness of the Sokoliska Limestone [cm]	Number of the Sokoliska Limestone layers	Distance between the first layer of the Sokoliska Limestone and the last layer of the Jasło Limestone [m]
Bukowiec	Silesian	2	9.1	7	5.5
Tyrawa Solna	Skole	2.40	8.9	6	2.5
Ascuns	Tarcău (Skole)	0.85	5.7	4	3.7
Teherău	Tarcău (Skole)	0.50	4.4	3	2.8

ied in detail the section from the Zagórz Limestone upwards in the eastern part of the Polish Carpathians, and placed the Zagórz Limestone in the foraminiferal P21 Zone. This is in agreement with the earlier work of Olszewska (1984).

CONCLUSIONS

The Sokoliska Limestone, as suggested by Koszarski and Żytko (1961), is a marker horizon of regional extent, present along the greater part of the Outer Carpathians, over a distance of ca. 550 km. It occurs in the section between the Jasło Limestone and the Zagórz Limestone, closer to the former. The total thickness of the limestone layers is less than 10 cm. The fine lamination in the Sokoliska Limestone differs from that in the other horizons in the greater abundance of non-calcareous material in the dark laminae. The laminated limestones within the Sokoliska Limestone horizon in some cases pass gradually to the neighbouring marly shales, in contrast to the other horizons, where the clastic interbeds display the characteristics of rapid deposition in short events during the longer episode of persistent, though seasonally oscillating and massive deposition of coccolith mud. The tests of planktonic foraminifers, though present, are rare. This is a clear difference with the Jasło Limestone, where foraminifers are abundant and with the Tylawa Limestones, where they are absent. The main coccolithophore taxon is *Cyclicargolithus floridanus*, as in the Jasło Limestone. Dinoflagellates or resting stages of dinoflagellates are common, but are not observed in the other limestone horizons.

The Sokoliska Limestone horizon, if taken into account as an independent precise marker, may assist in refining the stratigraphic framework of the Oligocene sequences of the Paratethys.

Acknowledgements

This study was financed by the National Science Centre (NCN) Grant 2011/01/D/ST10/04617 to AC. We gratefully offer thanks to Maciej Bojanowski and Mariusz Rospondek for their assistance during the field work and to Elżbieta Gaździcka and Jarosław Tyszka for helpful discussions. We appreciate helpful reviews by Titus Brustur and an anonymous reviewer and the revision of the English text by Frank Simpson.

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