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Stratigraphy and tectonics of a tectonic window in the Magura Nappe (Świątkowa Wielka, Polish Outer Carpathians)

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Abstract: The Świątkowa Wielka Tectonic Window belongs to the Grybów Nappe of the Fore-Magura Group of units. This tectonic window is located in the marginal part of the Magura Nappe and is composed of Oligocene — Sub-Grybów Beds as well as the Grybów Marl Formation. These beds have been correlated with the Oligocene deposits of other tectonic windows of the Grybów Nappe in Poland. Our research reveals that the Krosno beds' shally facies, which occur at the western termination of the Świątkowa Wielka Tectonic Window, belong to the Dukla succession. On the basis of calcareous nannoplankton analysis, the Grybów Marl Formation as well as the Krosno Beds belong to the NP23–NP24, and NP24 Zones, respectively. The structure of the Świątkowa Wielka Tectonic Window reveals a multi-stage evolution of the Magura Nappe overthrust onto their foreland.

Key words: Oligocene, Western Carpathians, Magura, Grybów and Dukla Nappes, duplex structure tectonic windows, biostratigraphy, calcareous nannoplankton.

Introduction

In the Polish sector of the Magura Nappe eleven tectonic windows were documented (Fig. 1A–C). These windows belong to the Grybów Nappe of the Fore-Magura Group of units (Oszczypko et al. 2008). This group of units, which occupy the intermediate position between the Silesian and Magura Nappes (Fig. 1C), contains transitional lithofacies, which linked the Silesian and Magura Basins (see Książkiewicz 1962; Bieda et al. 1963; Geroch et al. 1967; Koráb & Ďurkovič 1978; Olszewska 1981; Cieszkowski 1992, 2001; Oszczypko-Clowes & Oszczypko 2004; Oszczypko-Clowes & Ślączka 2006; Oszczypko-Clowes 2008). The Obidowa-Słopnice and Grybów Nappes occur in the tectonic windows. They are regarded as the western and southern prolongation of the Dukla Nappe (Cieszkowski 2001). These nappes are composed predominantly of Upper Eocene-Oligocene deposits (Oszczypko-Clowes & Oszczypko 2004; Oszczypko-Clowes & Ślączka 2006; Oszczypko-Clowes 2008).

The aim of this research was to establish the pecularities of the lithofacies and to determine the age of the calcareous nannoplankton of the Świątkowa Wielka Tectonic Window (SWTW) deposits, but also to plot their correlation with similar sediments from adjacent areas (Fig. 1B). On the basis of up-to-date geological mapping as well as old oil field drillings this work provides a new structural approach to this tectonic window.

Previous studies

In 1888 Uhlig described the dark variety of Menilite shales as "grybower Menilitschiefer" — already known in East Slovakia as the Smilno beds (Hauer 1859).

Over the period 1930–1932, while carrying out geological mapping in the Świątkowa Wielka area, Böhm (1933) discovered the Grybów black shales, which were established as the Cretaceous "Świątkowa facies", the oldest strata of the Magura succession. This concept was accepted by Świdziński (1934, 1947). However, in the early 1950's, the concept was questioned by K. Mrozek (see Kozikowski 1956) who, on the basis of geological mapping, drilling and micropaleontological data, documented that the "Świątkowa facies" are the equivalent of Menilite shales and occur in the tectonic window beneath the Magura Nappe.

The oldest sediments from the Grybów Nappe belong to the Jaworzynka Beds (Senonian–Paleocene) of the Mszana Dolna Tectonic Window (Fig. 1B), (see Oszczypko-Clowes & Oszczypko 2004). The most frequent rocks are Lower to Upper Eocene green, grey and black shales, with intercalations of medium- and fine-grained glauconitic sandstones, known as the Hieroglyphic Beds (Sikora 1960; 1970), Klęczany Beds (Kozikowski 1956) or Sub-Menilite Beds (Nemčok 1990; Nemčok et al. 1990). Towards the top they pass into greenish marls, a few meters thick, with an abundance of *Globigerina* representing the Late Eocene and corresponding to the horizon of the Sub-Menilite Globigerina Marls (SMGM), known from all units of the Outer Carpathians (Olszewska 1983; Leszczyński 1996, 1997; Oszczypko 1996; Oszczypko-Clowes 1998). Early Oligocene is represented by a series of roughly 150 meters of grey, dark green, black marls, and marly shales with intercalations of thin- to medium-bedded, micaceous, laminated sandstones and several thick-bedded, glauconitic sandstones. These deposits were established as the Sub-Grybów Beds by Kozikowski (1956). These beds pass upwards into Grybów Shales distinguished by Uhlig (1888) and named as Grybów Beds by Kozikowski (1956). In 1960 Sikora renamed them

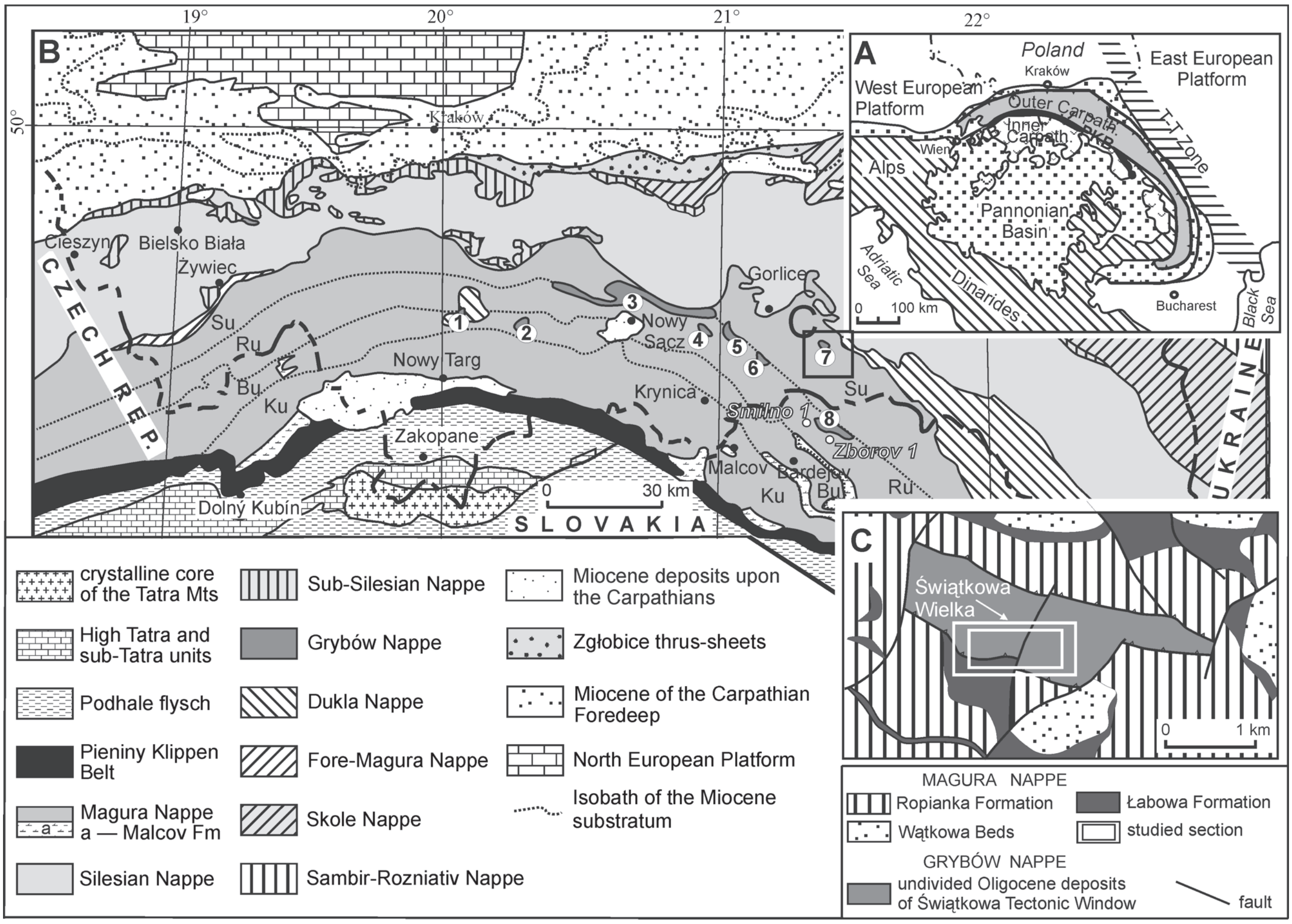

Fig. 1. A — Simplified tectonic scheme of the Alpine-Carpathian orogens. **B** — Tectonic sketch-map of the Outer Western Carpathians (based on Żytko et al. 1989, simplified). **C** — Tectonic sketch-map of the Światkowa Wielka Tectonic Window (based on Koszarski & Tokarski 1968, supplemented). Tectonic windows: 1 — Mszana Dolna, 2 — Szczawa, 3 — Klęczany-Pisarzowa, 4 — Grybów, 5 — Ropa, 6 — Uście Gorlickie, 7 — Świątkowa, 8 — Smilno.

again as the Grybów Shales. In the highest part of the Grybów Shales there are intercalations of black cherts and also brownish siliceous marls with cherty lenses. The lower boundary of the Grybów Shales can be found where grey-green marls from the Sub-Grybów Beds disappear, and where a sequence of brown and black marls appear.

The age of the youngest sediments of the Grybów Nappe is generally regarded as Oligocene. The foraminiferal studies were conducted by Kozikowski (1956), Blaicher (in Sikora 1960, 1970), and Olszewska (1981). According to Olszewska (1981), the Sub-Grybów Beds (Klęczany and Ropa Window) as well as the Grybów Shales (Klęczany and Mszana Dolna Windows) are of Oligocene age.

Biostratigraphical studies based on nannofossils were initiated by Smagowicz (see Burtan et al. 1992; Cieszkowski 1992) in the Klęczany Tectonic Window. She recognized nannofossil associations from the Sub-Grybów Beds, which were characteristic for latest Eocene–Early Oligocene. More recently, a detailed calcareous nannoplankton study of the Grybów Nappe was carried out in Mszana Dolna and also in the Szczawa Tectonic Windows (Oszczypko-Clowes & Oszczypko 2004), as well as in the Grybów (Oszczypko-Clowes & Ślączka 2006) and Ropa (Oszczypko-Clowes 2008) Tectonic Windows. In the Mszana Dolna Tectonic Window the youngest deposits were assigned to the NP24 (Krosno Beds of the Dukla Nappe) and NP23–NP25 (Krosno (Cergowa) Beds of the Grybów Nappe) Zones. Similar nannoplankton ages were also established in the Grybów Nappe of the Szczawa Tectonic Window. Zones NP22–NP24 were determined in the Grybów Shales, whereas the Krosno (Cergowa) Beds belong to Zone NP24 (see Oszczypko-Clowes & Oszczypko 2004). The Grybów Shales of the Grybów Tectonic Window were assigned to Zone NP24, while the Krosno (Cergowa) Beds were included in Zones NP24–NP25 (Oszczypko-Clowes & Ślączka 2006). Simultaneously these authors proposed the Grybów Marl Formation (GMF) as a more appropriate new name due to its lithological development. In the Ropa Tectonic Window the NP22–NP24 Zone interval was determined in the GMF, whereas the Krosno Beds belong to Zone NP25 (Oszczypko-Clowes 2008). On the basis of dinoflagellates, Barski (in Bojanowski 2007b) determined the middle Rupelian age of the Krosno shales of the SWTW.

In the adjacent Dukla Nappe calcareous nannoplankton studies were, so far, also sporadic and carried out by Smagowicz (Olszewska & Smagowicz 1977). Foraminiferal studies were lately conducted by Olszewska (1983). They proposed the biostratigraphical scheme of the Upper Cretaceous–Paleogene deposits from the Dukla Nappe; which was based on foraminiferal and calcareous nannoplankton investigations. A detailed stratigraphic study of the Krosno Beds from the Dukla Nappe in the Mszana Dolna Tectonic Window was carried out by Oszczypko-Clowes & Oszczypko (2004).

In the Fore-Magura, Ždánice-Subsilesian and Pouzdřany Units of the Czech sector of the Outer Carpathians the Menilite and Krosno lithofacies were studied by Švábenická et al. (2007).

In the Ukrainian Carpathians the Vezhany Unit of the Marmarosh Flysch can be regarded as the equivalent of the Grybów successions of the Outer Western Carpathians (Oszczypko et al. 2005). In this succession the Dusina marls have the same age (NP24) and lithofacies development as the Grybów Marl Formation in Poland.

Geological setting

The Świątkowa Wielka Tectonic Window, up to 1 km wide and up to 3.5 km long, is located in the Beskid Niski Range ca. 3–3.5 km southwest from the front of the Magura Nappe (Fig. 1C). This tectonic window was discovered by Kozikowski (1956, 1958). The geological mapping of the surrounding area was carried out by Koszarski & Tokarski (1968). The Oligocene strata of the Grybów Nappe in this tectonic window are bound by the Upper Cretaceous–Paleocene Ropianka Formation (Inoceramian Beds), Lower/Middle Eocene Łabowa Shale Formation (Variegated Shales) and the Wątkowa Beds (Upper Eocene–Oligocene) of the Magura Nappe (Koszarski & Tokarski 1968; Kopciowski 2007). Based on geological mapping and drillings, Tokarski (1965) described the structure of the Świątkowa Wielka Tectonic Window. According to his interpretation, the present structure of the tectonic window, developed when the Magura and Grybów Nappes were overthrust onto the eroded Dukla Nappe. This was followed by the refolding of the Magura and Grybów Nappes together.

The Oligocene deposits of the SWTW are strongly deformed and are often in an overturned position (Fig. 2). These deposits belong to the Sub-Grybów Beds, Grybów Marl Formation (GMF) (see Kozikowski 1956; Koszarski & Tokarski 1968; Koszarski & Koszarski 1985). The Krosno Beds occupy a special position with a block of "exotic" limestones, located at the boundary between the Magura and Grybów Nappes (see Mastella & Rubinkiewicz 1998; Bojanowski 2007a,b).

The studied section is exposed along the Krokowy Stream, which is a triburaty of the Świerzówki Stream and Wisłoka River (Fig. 2).

The oldest Eocene deposits of the Grybów succession probably belong to the Hieroglyphic Beds known only from the borehole Sw4 (Fig. 3). Higher up in the succession the Sub-Grybów Beds occur at least 100 m thick, which are exposed in the middle flow of the Krokowy Stream and pieced in borehole Sw4 (Fig. 3). The basal portion of the Sub-Grybów Beds is composed of grey and green, thin-bedded marls, yellowish as weathered, and which probably belong to the Sub-Menilite Globigerina Marls. These are followed by grey, greenish, black marls (Fig. 4A) and greenish non-calcareous shales with intercalations of thin- to medium-bedded sandstones (Fig. 4B). The rocks of these Sub-Grybów Beds pass upwards into the Grybów Marl Formation the most typical Oligocene sediments of the SWTW, known both from exposures and all boreholes. These beds up to 200 m thick are composed of thick-bedded sandstones and marls. In general these beds display upward sequences of thickening and coarsening. The thick-bedded sandstones (80–160 cm) show Tabc Bouma's interval; they are coarse- to medium-grained with large flute casts. The transition from the Sub-Grybów to the GMF is manifested by a few packets 5–7 m thick of massive dark grey marls, brown as weathered (Fig. 4C). These marls are followed by thick packets of grey, dark grey, green shales and brown Menilite-type shales (Fig. 4D). The middle part of the formation contains thick-bedded, light coloured, medium-grained, quartz rich, laminated, sandstones (Fig. 4E) of the "Kliwa-like sandstone" (see Nemčok et al. 1990), grey marls and shales with an intercalation of laminated Tylawa-type limestone (Fig. 4F). In the upper part of the formation there are also thick-bedded, muscovitic sandstones of the Cergowa type and thin-bedded sandstones (Fig. 5A,B,E). These sandstones are subordinately intercalated by dark grey, platty (Fig. 5C), massive (Fig. 5D) and thin-bedded marls (Fig. 5E). The massive marls form 3- to 8 m thick packets. Sometimes these marls are accompanied by thin-bedded lenses of ferruginous dolomites (siderites). In the upper part of the formation the grey shales (Fig. 6A,B) are intruded by sandstone dykes.

The youngest deposits of the SWTW belong to the Krosno Beds, exposed in the upper course of the Krokowy Stream, at the western termination of the tectonic window (Fig. 2). From the east these beds are separated from the Sub-Grybów Beds by a thrust fault. These strongly deformed beds, display a thinning and fining upward sequence and they are composed of marly mudstones and shales, with a tablet separateness (Fig. 6C,D). They often form packets up to several-dozen meters thick. The sandstone intercalations are usually thin- and very thin-bedded. In the middle part of the section the Krosno shales contain beds of tectonically sheared ferruginous dolomites, and beds of laminated limestones up to 35 cm thick (Fig. 6E). In the contact zone between the Krosno shales and the variegated shales belonging to the Magura Nappe, there are well-known blocks of "exotic" limestones (Koszarski & Koszarski 1985) — GPS position: N 4931′671, E 2124′377. According to Mastella & Rubinkiewicz (1998) these limestones are of Miocene age. Recently, Bojanowski (2007a,b) documented that these limestones are a carbonate build-up and composed of "cold seep-related carbonate intraformational breccia" (Fig. 6F).

Calcareous nannofossils

Methods and sample preparation

The field work in the SWTW was carried out between 2003 and 2005. For the purpose of the biostratigraphic re-

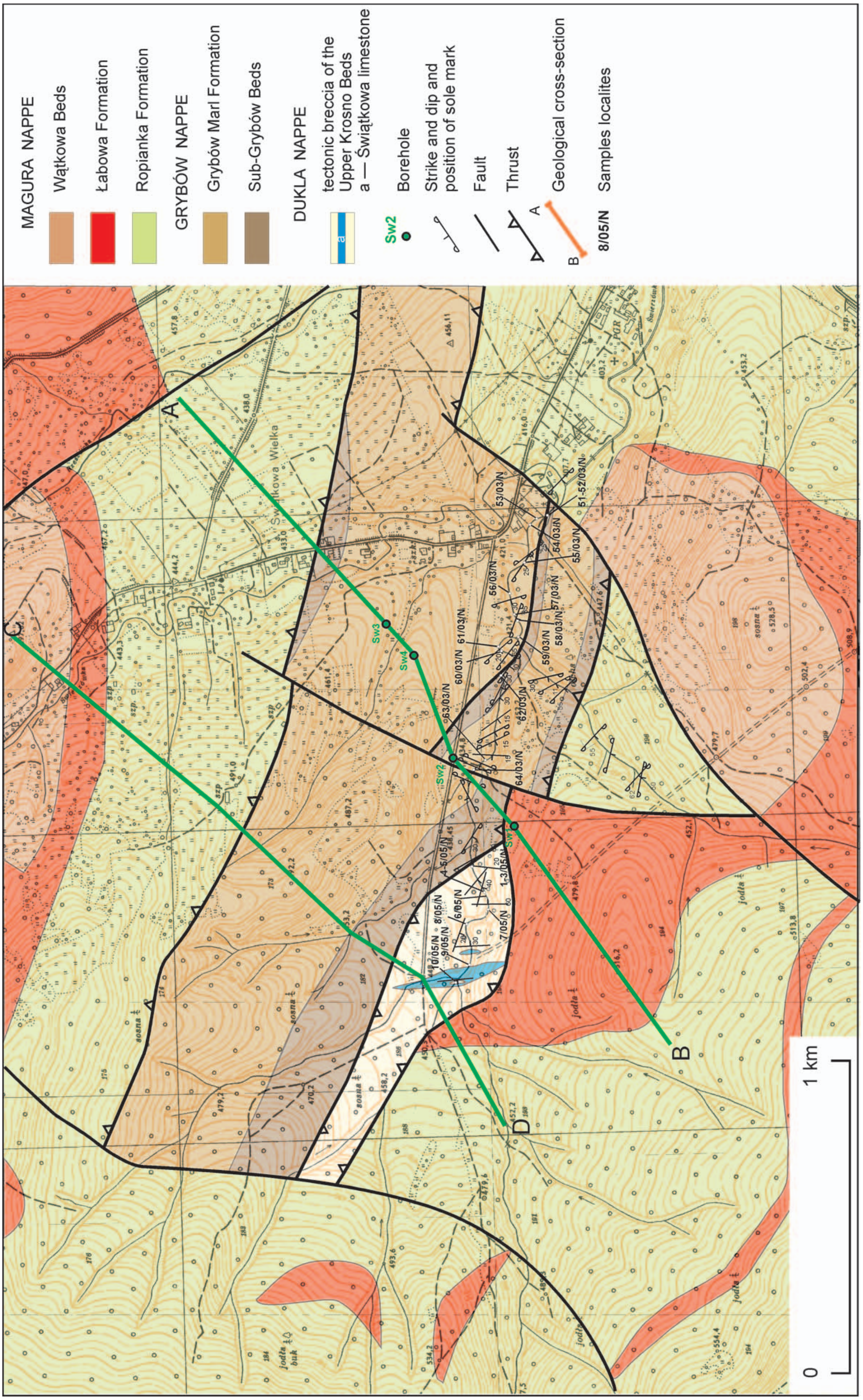

Fig. 2. Geological map of the Świątowa Wielka Tectonic Window, with location of sampled sections (party after Koszarki & Tokarski (1968, simplified)).

Sw1 BOREHOLE alt. 452.5 m a.s.l.	
N 49 31 35,58, E 21 24 53,05	
Magura Nappe	
0–86	Variegated Shales (abowa Sh. Fm)
86–101	Inoceramian Beds (Ropianka Fm)
101–156	Variegated Shales (abowa Sh. Fm)
156–272	Inoceramian Beds (Ropianka Fm)
Grybów Nappe	
272–491	Grybów Shales
Dukla Nappe	
491–529	Krosno Beds

Sw2 BOREHOLE alt. 440 m a.s.l.	
N 49 31 42, 01, E 21 25 05,54	
Grybów Nappe	
0–74	Grybów Shales
Magura Nappe	
74–108	Variegated Shales (abowa Sh. Fm)
108–164	Inoceramian Beds (Ropianka Fm)
Dukla Nappe	
164–514	Krosno Beds

Sw3 BOREHOLE	
445 m a.s.l.	
N 49 31 48,41, E 21 25 20,49	
Grybów Nappe	
0–137	Grybów Shales
Magura Nappe	
137–146	Variegated Shales (abowa Sh. Fm)
Grybów Nappe	
146–159	Grybów Shales
Magura Nappe	
159–199	Variegated Shales (abowa Sh. Fm)
199–250	Submarine slump of tectonic breccia
Dukla Nappe	
250–512	Krosno Beds

Sw4 BOREHOLE	
alt. 440 m a.s.l.	
N 49 31 45, 19, E 21 25 20,49	
Grybów Nappe	
0–155	Grybów Shales
155–218	Hieroglyphic Beds
218–252	Sub-Grybów Beds
252–267	Hieroglyphic Beds
Dukla Nappe	
277–403	Krosno Beds

Fig. 3. Geological profiles of boreholes (after Nawrocka-Gierat & Wdowiarz 1975, CAGPIG).

search, 26 samples were collected from the Krokowy Stream where a continuous sequence is exposed (Fig. 2).

All the samples were prepared using the standard smear slide technique for light microscope (LM) observations. The investigation was carried out under LM-Nikon — Eclipse E 600 POL, at a magnification of 1000× using parallel and crossed nicols. Several of the specimens photographed in LM are illustrated in Fig. 7.

Results

The majority of the examined samples yield moderately preserved nannofossil assemblages. The relative abundance of samples is usually medium to low (Fig. 8).

Sub-Grybów Beds. All the samples 51-52/03/N and 62/03/N, collected from either non-calcareous or slightly calcareous shales and marls were barren of nannofossils (Fig. 8).

The Grybów Marl Formation. There are two distinctive nannofossil assemblages within the GMF. The first association was described from the following samples: 58-61/03/N (Fig. 2) whereas the other is characteristic for samples 53-57/03/N and 63-64/03/N.

The nannofossils from samples 58-61/03/N are reasonably well-preserved, though the assemblages reveal low diversity and a medium-to-high number of specimens. The assemblage is characterized by the presence of *Coccolithus eopelagicus*, *Coccolithus pelagicus*, *Cyclicargolithus floridanus*, *Dictyococcites bisectus*, *Discoaster tanii*, *Discoaster tanii nodifer*, *Isthmolithus recurvus*, *Lanternithus minutus*, *Neococcolithes dubius*, *Reticulofenestra dictyoda*, *Reticulofenestra ornata*, *Sphenolithus moriformis*, *Sphenolithus radians*. The important feature of this assemblage is the abundant presence of *Reticulofenestra ornata*.

Samples from 53-57/03/N and 63-64/03/N contain a relatively rich, abundant and well-preserved assemblage. The nannofosil association is characterized by co-occurenec of *Coccolithus eopelagicus*, *Coccolithus pelagicus*, *Cyclicargolithus abisectus*, *Cyclicargolithus floridanus*, *Dictyococcites bisectus*, *Reticulofenestra lockerii*, *Reticulofenestra minuta*, *Reticulofenestra ornata*, *Sphenolithus dissimilis*, *Sphenolithus moriformis*, *Zygrhablithus bijugatus*. The most important species are *Cyclicargolithus abisectus* and *Sphenolithus dissimilis*.

Krosno Beds. The autochthonous assemblage of 1-10/05/N samples is characterized by the presence of *Coccolithus eopelagicus, Coccolithus pelagicus*, *Cyclicargolithus abisectus*, *Cyclicargolithus floridanus*, *Dictyococcites bisectus*, *Neococcolithes dubius*, *Reticulofenestra dictyoda*, *Reticulofenestra lockerii*, *Reticulofenestra minuta*, *Reticulofenestra ornata*, *Sphenolithus dissimilis*, *Sphenolithus moriformis*. The most abundant are *Cyclicargolithus abisectus*, *Cyclicargolithus floridanus*, *Dictyococcites bisectus* and *Coccolithus pelagicus*. The youngest species determining the age are *Cyclicargolithus abisectus* and *Sphenolithus dissimilis*. Additionally, some of the samples contained *Helicosphaera euphratis*, *Helicosphaera compacta*, *Pontosphaera multipora*, *Pontosphaera plana*.

Biostratigraphical interpretation

For the purpose of biostratigraphic analysis the standard zonation of Martini (1971) was used. In the cases where index species were not observed it was necessary to use the secondary index and characteristic species.

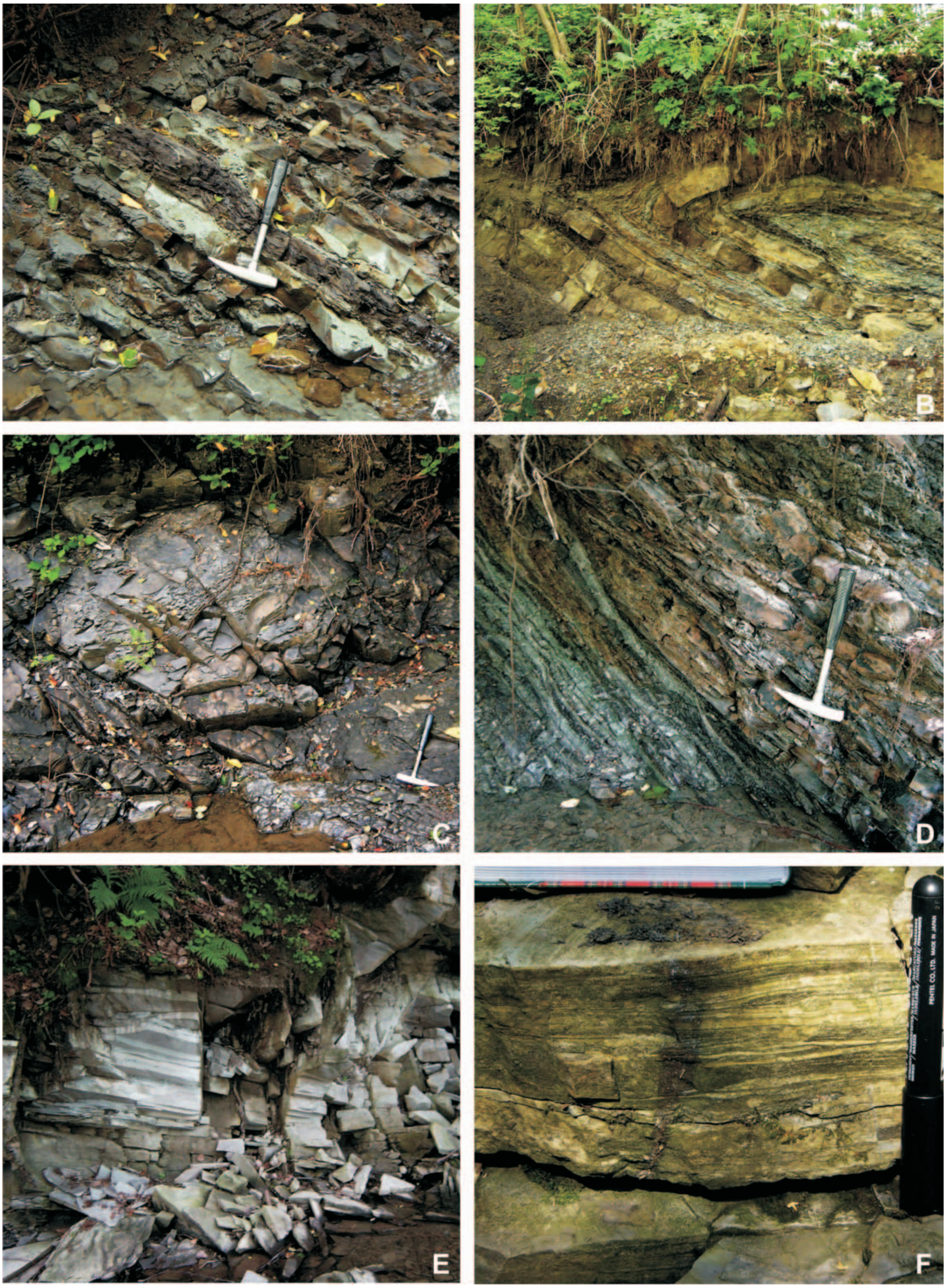

Fig. 4. Exposures of the Grybów succession in the Krokowy Stream, Świątkowa Wielka. **A** — Grey, greenish and black marls of the Sub-Grybów Beds; **B** — Grey and greenish non-calcareous shales with intercalation of the medium-bedded sandstones of the sub-Grybów Beds — imbricated anticline with west-dipping hinge plane; Gybów Marl Formation; **C** — Dark brown, thick-bedded massive marls of basal portion of the formation; **D** — Grey, greenish and brown (Menilite type) shales; **E** — Thick-bedded, light quartz-rich sandstones, with graded and parallel lamination; **F** — Tylawa laminated limestone.

Fig. 5. Exposures of the Grybów Marl Formation in the Krokowy Stream, Świąkowa Wielka. **A** — Base of thick-bedded sandstone with big flute-casts, displaying paleotransport from SE position; **B** — Medium-bedded, very fine- and fine-grained sandstones with parallel and convolute laminations; **C** — Grey platy marls, with dark grey bed at the base; **D** — Dark grey, thick-bedded massive marls; **E** — Grey thin-bedded marls; **F** — Base of thick-bedded sandstone with big, loaded flute-casts, displaying paleotransport from SE, overturned position.

Fig. 6. Exposures of the Grybów and ?Dukla succession in the Krokowy Stream, Świątkowa Wielka. Grybów Marl Formation. **A** — Dark grey massive marls-stone with clastic dyke; **B** — Grey marly shales with intercalations of medium-bedded, fine-grained sandstones; Krosno Beds of the Dukla succession; **C** — Marly shales and marl-stones of the lower portion of the beds of the Dukla succession; **D** — Strongly folded overturned marly shales; **E** — Laminated limestone intercalation; **F** — Block of brecciated limestones.

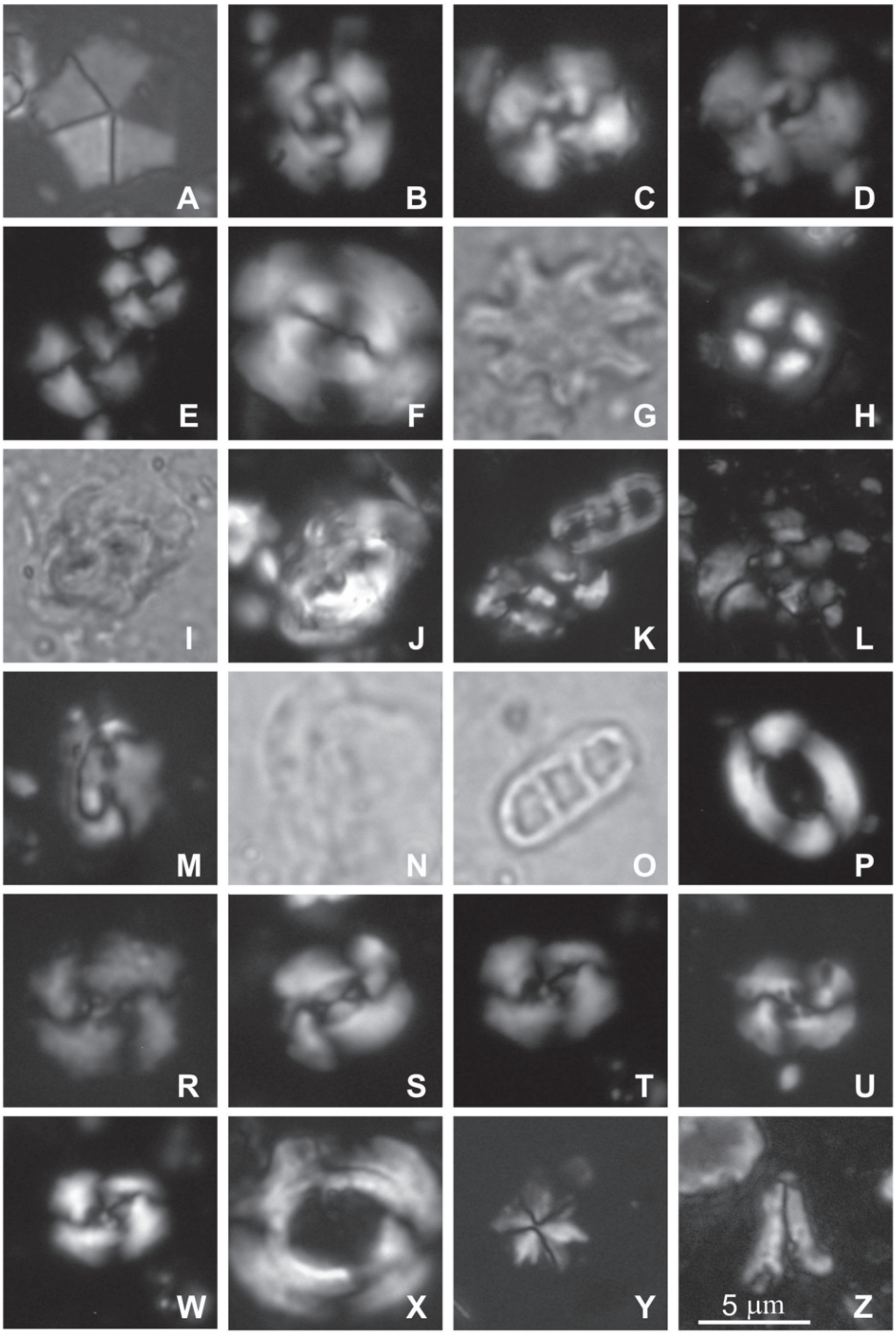

Fig. 7. LM microphotographs of calcareous nannofossils. **A** — *Braarudosphaera bigelowii*, Grybów Marl Fm, sample 54/03/N; **B** — *Cyclicargolithus abisectus*, Grybów Marl Fm, sample 53/03/N; **C** — *Cyclicargolithus abisectus*, Grybów Marl Fm, sample 61/03/N; **D** — *Cyclicargolithus abisectus*, Krosno Beds, sample 1/05/N; **E** — *Cyclicargolithus floridanus*, Krosno Beds, sample 10/05/N; **F** — *Dictyococcites bisectus*, Krosno Beds, sample 10/05/N; **G** — *Discoaster* sp., Krosno Beds, sample 2/05/N; **H** — *Ericsonia formosa*, Grybów Marl Fm, sample 54/03/N; **I** — *Helicosphaera compacta*, Grybów Marl Fm, sample 55/03/N; **J** — *Helicosphaera compacta*, Grybów Marl Fm, sample 55/03/N; **K** — *Helicosphaera euphratis*, Grybów Marl Fm, sample 55/03/N; **L** — *Helicosphaera euphratis*, Krosno Beds, sample 10/05/N; **M** — *Helicosphaera recta*, Grybów Marl Fm, sample 55/03/N; **N** — *Helicosphaera recta*, Grybów Marl Fm, sample 55/03/N; **O** — *Isthmohlithus recurvus*, Grybów Marl Fm, sample 58/03/N; **P** — *Pontosphaera lateliptica*, Grybów Marl Fm, sample 57/03/N; **R** — *Reticulofenestra lockerii*, Grybów Marl Fm, sample 64/03/N; **S** — *Reticulofenestra lockerii*, Krosno Beds, sample 7/05/N; **T** — *Reticulofenestra ornata*, Grybów Marl Fm, sample 58/03/N; **U** — *Reticulofenestra ornata*, Grybów Marl Fm, sample 60/03/N; **W** — *Reticulofenestra ornata*, Grybów Marl Fm, sample 61/03/N; **X** — *Reticulofenestra umbilica*, Krosno Beds, sample 7/05/N; **Y** — *Sphenolithus dissimilis*, Krosno Beds, sample 2/05/N; **Z** — *Zygrhablithus bijugatus*, Krosno Beds, sample 10/05/N.

	O L I G O C E N E																							
	GRYBÓW NAPPE														DUKLA NAPPE									
Tectonic units/lithostratigraphy	SUB-GRYBÓW BEDS			GRYBÓW MARL FORMATION											KROSNO BEDS									
Nannofossils zones Martini (1971)				NP 24	NP 24	NP 24	NP 24	NP 24	NP 23		NP 23	NP 23	NP 24	NP 24	NP 24	NP 24		NP 24		NP 24	NP 24	NP 24	NP 24	NP 24
Sample number	51/03/N	52/03/N	62/03/N	53/03/N	54/03/N	55/03/N	56/03/N	57/03/N	58/03/N	59/03/N	60/03/N	61/03/N	63/03/N	64/03/N	1/05/N	2/05/N	3/05/N	4/05/N	5/05/N	6/05/N	7/05/N	8/05/N	9/05/N	10/05/N
Braarudosphaera bigelowii	–	–	–		X	X				–	X		–	X			–		–		X		X	X
Coccolithus eopelagicus	–	–	–		X	X	X	X	X	–	X	X	–	X	X		–	X	–	X	X	X	X	X
Coccolithus pelagicus	–	–	–	X	X	X	X	X	X	–	X	X	–	X	X		–	X	–	X	X	X	X	X
Cyclicargolithus abisectus	–	–	–	X	X	X	X	X		–			–	X	X	X	–	X	–	X	X	X	X	X
Cyclicargolithus floridanus	–	–	–	X	X	X	X	X	X	–	X	X	–	X	X	X	–	X	–	X	X	X	X	X
Cyclicargolithus luminis	–	–	–							–		X	–			X	–		–					
Dictyococcites bisectus	–	–	–	X	X	X	X	X	X	–	X	X	–	X	X	X	–	X	–	X	X	X	X	X
Discoaster sp.	–	–	–						X		X	X	–			X	–		–					
Discoaster tanii	–	–	–						X		X	X	–				–		–					
Discoaster tanii nodifer	–	–	–						X		X	X	–				–		–					
Ericsonia fenestrata	–	–	–		X	X	X	X	X	–			–	X		X	–		–		X		X	X
Ericsonia formosa	–	–	–		R	R	R			–			–				–		–					
Helicosphaera compacta	–	–	–			X			X	–			–			X	–		–					
Helicosphaera euphratis	–	–	–			X			X	–			–				–		–					X
Helicosphaera recta	–	–	–			X			X	–			–				–		–					
Isthmolithus recurvus	–	–	–		X	X	X	X	X	–	X	X	–	X	X	X	–		–		X		X	X
Lanternithus minutus	–	–	–		R	R	R	R	X	–	X	X	–	X		R	–		–		X		X	X
Neococcolithes dubius	–	–	–			X			X		X	X	–			X	–		–					
Pontosphaera lateliptica	–	–	–					X					–				–		–					
Pontosphaera plana	–	–	–										–				–		–					
Reticulofenestra dictyoda	–	–	–		X		X	X	X	–	X	X	–	X			–		–		X		X	X
Reticulofenestra lockerii	–	–	–		X				X	–		X	–	X			–		–		X		X	X
Reticulofenestra minuta	–	–	–		X	X		X		–	X	X	–	X		X	–		–		X		X	X
Reticulofenestra ornata	–	–	–	X	X	X	X	X	X	–	X	X	–	X		X	–		–		X		X	X
Reticulofenestra umbilica	–	–	–						R	–	R	R	–	R			–		–		R		R	R
Sphenolithus dissimilis	–	–	–							–			–				–		–					
Sphenolithus moriformis	–	–	–	X	X	X		X	X	–	X	X	–	X		X	–		–		X		X	X
Sphenolithus pseudoradians	–	–	–						X	–		X	–				–		–					
Sphenolithus radians	–	–	–		R	R	R		R	–	R	R	–			R	–		–					
Transversopontis pulcheroides	–	–	–		X				X	–			–				–		–					
Zygrhablithus bijugatus	–	–	–	X	X	X	X	X	X	–	X	X	–	X	X	X	–	X	–	X	X	X	X	X

Fig. 8. Calcareous nannofossil distribution in the Oligocene deposits of the SWTW.

In the studied area the nannofossil association described from the GMF allow us to determine Zones NP23 and NP24, which represent the Kiscellian stage in the Central Paratethys Regional Scheme (Fig. 9). The zone assignment of NP23 is based on the abundant presence of *Reticulofenestra ornata* followed by the last occurrence of *Reticulofenestra umbilica*, which marks the upper limit of Zone NP22. According to Nagymarosy & Voronina (1992) *Reticulofenestra ornata* is an endemic species, and its abundant presence is a characteristic event in Zone NP23 of the Paratethys region, only. The FO of *Cyclicargolithus abisectus* is usually found close to the FO of *Sphenolithus ciperoensis* (zonal marker for the lower boundary of Zone NP24) and thus can be used to approximate the boundary of NP23 and NP24 (Martini & Műller 1986). In addition, *Sphenolithus dissimilis* Bukry & Percival was also observed. The FO of these species is characteristic for Zone NP24 (see Perch-Nielsen 1985).

Melinte (2005) identified the FO of *Cyclicargolithus abisectus* towards the lower part of the NP23, well below the FO of *Sphenolithus ciperoensis*. However, the absence of *Transversopontis fibula*, *Orthozygus aureus*, *Lanternitus minutus* and *Chiasmolithus oamaruensis*, which has the LO in the upper part of NP23 (see Melinte 2005) makes it possible to include the given samples in Zone NP24.

Such an age determination is coeval with the results of Garecka (2008) from the Silesian Nappe. Almost the same nannofossil associations were described by Švábenická et al. (2007) from the Fore-Magura, Ždánice-Subsilesian and Pouzdřany Units of the Czech sector of the Outer Carpathians.

Paleoecology

The described assemblages are characterized by the presence of both temperate (*Dictyococcites bisectus*, *Cyclicargolithus floridanus*, *Coccolithus pelagicus*, *Coccolithus eopelagicus*) and typically cold-water taxa such as *Isthmolithus recurvus*, *Reticulofenestra lockerii*, *Reticulofenestra ornata* (see Wei & Wise 1990; Nagymarosy & Voronina 1992; Oszczypko-Clowes 2001). The latter two species had their first occurrence in Zone NP23, which probably indicates another drop in the temperature of water masses.

The assemblages are scarce in species of *Helicosphaera*, *Sphenolithus* and *Discoaster* (Figs. 7, 8). These species are typical warm water indicators and occur only sporadically.

The distribution of *Reticulofenestra ornata*, *Transversopntis fibula* and *Transversopntis latus* is limited not only in time

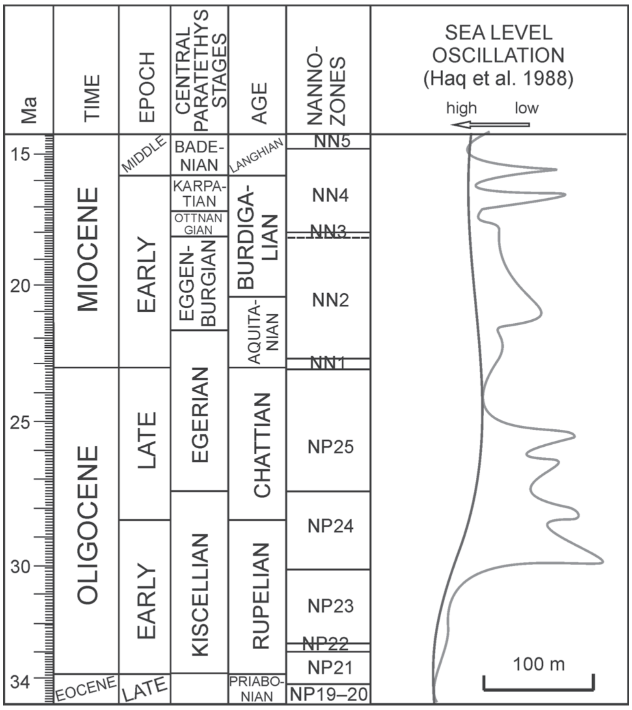

Fig. 9. Correlation of Oligocene and Early Miocene stages (Berggren et al. 1995) with Central Paratethys stages (Cicha et al. 1998), modified.

but also in space (to the Paratethys region). The above-mentioned association is strictly characteristic for Zone NP23 (Nagymarosy & Voronina 1992).

So far the species *Transversopntis fibula* and *Transversopntis latus* were not found in the nannofossil association from GMF from the SWTW. At the same time the assemblages of GMF are characterized by an abundance of *Reticulofenestra ornata* which prove that in the higher part of NP23 there was a distinct drop in salinity, which led to the development of the brackish-water environment (see Nagymarosy & Voronina 1992; Krhovský et al. 1992; Oszczypko-Clowes 2001; Soták et al. 2001; Melinte 2005; Švábenická et al. 2007). This event is associated with the complete isolation of the Paratethys (Baldi 1980; Rusu 1988; Rögl 1999) and can be traced in both the Central (Chert Member and Dynów Marl of Menilite Formation in Ždánice-Pouzdřany Unit, see Krhovský 1981a,b; Krhovský et al. 1992; Soták 2001) and Eastern Paratethys (Polbinian horizon, see Nagymarosy & Voronina 1992).

Close to the NP23/24 boundary, open-marine, calcareous nannofossil assemblages have developed again. Zone NP24 is characterized by the presence of rich and highly diversified assemblages dominated by mid-latitudinal species (*Dictyococcites bisectus*, *Coccolithus eopelagicus*, *Coccolithus pelagicus*, *Cyclicargolithus abisectus*, *Cyclicargolithus floridanus*).

At the same time the typical low-salinity species of *Reticulofenestra ornata* are becoming much less abundant. Such assemblages indicate that, at the turn of NP23/24, the normal salinity condition in the Grybów Sub-basin was restored and the connection between the Paratethys and the North Sea as well as with the Mediterranean region was re-established (see Baldi 1980; Rusu 1988; Rögl 1999; Popov et al. 2003; Schulz et al. 2005).

Tectonics

The SWTW (Figs. 2, 10) is located in axial part of the broad, NWN-SES trending Krępna-Świątkowa Wielka anticline; composed of the Ropianka Formation (Inoceramian Beds, Late Cretaceous–Paleocene). From the south and north refolded, broad synclinal zones accompany this anticline. The moderate inclined limbs of the anticline are composed of narrow strips of the variegated shales of the Łabowa Shale Formation (Paleocene–Middle Eocene), while relatively broad and elongated synclines are filled by thick-bedded glauconitic sandstones of the Wątkowa Beds (Late Eocene–Oligocene) and Supra-Magura (Budzów) Beds (Oligocene).

The rocks of Grybów Nappe are arranged in several narrow NW-SE trending, imbricated folds. The axes of the anticlines and synclines plunge to the NW and SE (Mastella & Rubinkiewicz 1998). The best exposures of the nappe are displayed in the Krokowy Stream (Fig. 2). The SWS dipping, mainly overturned beds of the GMF and Sub-Grybów Beds form small pseudoanticlines and pseudosynclines. These small structures are incorporated in seven mapped-scale (1 : 10,000) thrust sheets (slices, see Mastella & Rubinkiewicz 1998). Using the same scale we mapped a narrow anticline, up to 50 m wide composed of the Sub-Grybów Beds, while the limbs of the fold belong to the GMF. The hinge of the anticline displays a horizontal hinge surface (Fig. 4B). The axes of the anticline (W–E) gently (10°) plunge to the W. The hinge of the anticline is thrust over the northern overturned limb. The southern limb of the fold gently dips to the west. Going up ca. 400 m in the Krokowy Stream we cross the hinge of the syncline, inclined (80°) to the SW and overturned (Fig. 5A,F). The southern limb of the syncline is composed of GMF and Sub-Grybów Beds. Towards the west we cross the WSW dipping (250°/60°) tectonic contact of the Sub-Grybów Beds with Krosno shales. The Krosno shales are exposed in the upper course of the Krokowy Stream for a distance of ca. 500 m. These beds show very strongly ductile deformation (kind of tectonic mélange), with small folds (axes WSW–ENE, EW–SE and sub-horizontal hinge surfaces), several shear zones, and folded boudinaged layers. Sometimes the character of deformation is chaotic (Fig. 6D). In the upper part of exposures the Krosno shales contain boudines and beds of ferro-dolomitic limestones, beds of laminated limestones and brecciated carbonate-build-up (Bojanowski 2007a,b). These limestones contact with gently south dipping red shales of the Łabowa Formation.

On the basis of our field and archival drilling data (Fig. 3, see also Nawrocka-Gierat & Wdowiarz 1975, CGA PIG) two geological cross-sections, more or less perpendicular to the boundary of the tectonic window, have been constructed (Fig. 10). These cross-sections illustrate a relationship of the Grybów Nappe to the Magura Nappe and basement of these units.

The sole thrust of the Grybów Nappe was reached at a depth of 74 m (Sw2 borehole) through to 491 m (Sw1 borehole), which's 366 m a.s.l. and 38.5 m b.s.l., while the top of the

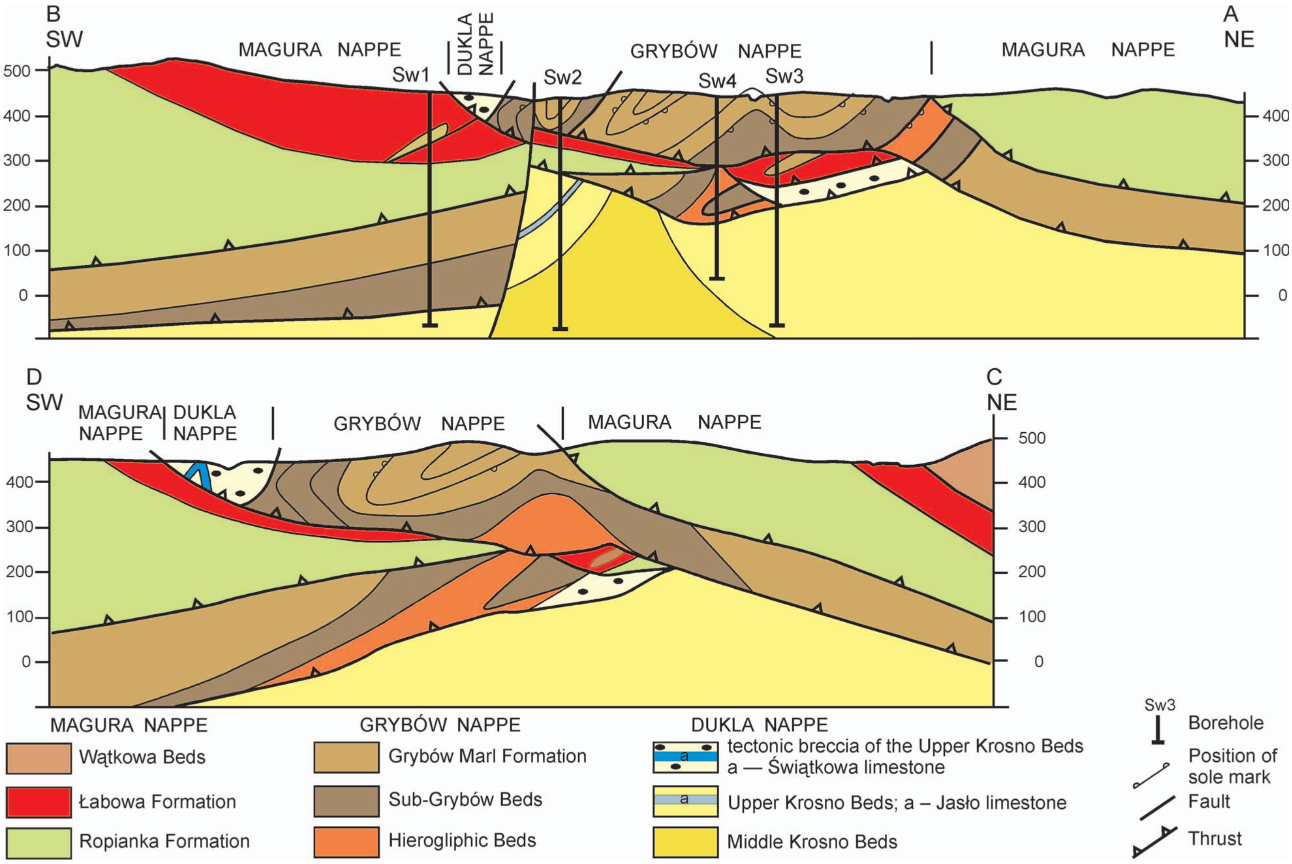

Fig. 10. Geological cross-sections through the Świątkowa Wielka Tectonic Window.

Dukla Nappe was pierced at a depth of 164 m (Sw2) to 491 m (Sw1), 276 m a.s.l. to 38.5 m b.s.l. (Figs. 3, 10). Between the Grybów Nappe and Dukla Nappe the 62–90 m block of the Magura Nappe was found in boreholes Sw2 and Sw3 (Figs. 3, 10). The pierced beds belong to variegated shales (Łabowa Shale Formation) and the Ropianka Formation of the Magura Nappe. In borehole Sw3 inside the variegated shales, a 13 m thick block of GMF was found. In this borehole beneath the lower portion of the variegated shales and above the top of the upper Krosno Beds of the Dukla Nappe, a 51 m packet of "fossil slump" was drilled (Tokarski 1965). At same time in the borehole Sw4 the mentioned block of the Magura Nappe is replaced by Hieroglyphic and Sub-Grybów Beds probably both belonging to the Grybów Nappe.

The analysis of the cross-section (Fig. 8) anabled new structural interpretation of the SWTW window:

1. The Grybów Nappe of the SWTW and Magura Nappe of the northern part of the winow are flatly overthrust upon the Grybów and Magura Nappes of the southern part of SWTW.

2. The very strongly deformed Krosno shales exposed in the upper course of the Krokowy Stream and edged between the Magura Nappe and Sub-Grybów Beds of the Grybów Nappe are in the "out of sequence" position.

3. The brecciated rocks of the "fossil slump" (Figs. 3, 10) edged between the Variegated Shales of the Magura Nappe and Upper Krosno Beds of the Dukla Nappe in the boreholes Sw3, probably represent a detached fragment of the Dukla Nappe.

4. The present-day structure of the SWTW is a result of the retro-thrust of the Magura and Grybów Nappes towards the south. The amplitude of this ovethrust is at least 1.5 km.

Disscusion

In the following tectonic windows (Grybów Nappe, Mszana Dolna, Szczawa, Grybów, Ropa and Świątkowa Wielka) we found the Oligocene strata belonging to the Sub-Grybów Beds, Grybów Marl Formation (GMF) and Krosno Beds (Fig. 11). All these strata occur above the Sub-Menilite Globigerina Marls. The oldest strata represented by Hieroglyphic Beds were probably pierced in the Sw4 borehole in the Światkowa Wielka (Gierat-Nawrocka & Wdowiarz 1975). The lower part of the Grybów succession, belonging to the Sub-Grybów Beds, is dominated by non-calcareous grey and greenish mudstones and shales, with packets of the black and brown Menilite-type shales.

The most typical deposits of the tectonic windows belong to the GMF. This formation is composed of dark grey, black and dark brown muddy marls. In the lower part of the formation the marls with intercalations of thin- to medium-bedded turbidite sandstones are present, while the upper part is dominated by thick-massive marl and thick-bedded Cergowa-type sandstones. Subordinately, this formation contains lenses or beds of the ferruginous dolomitic limestones (Fig. 11). In the

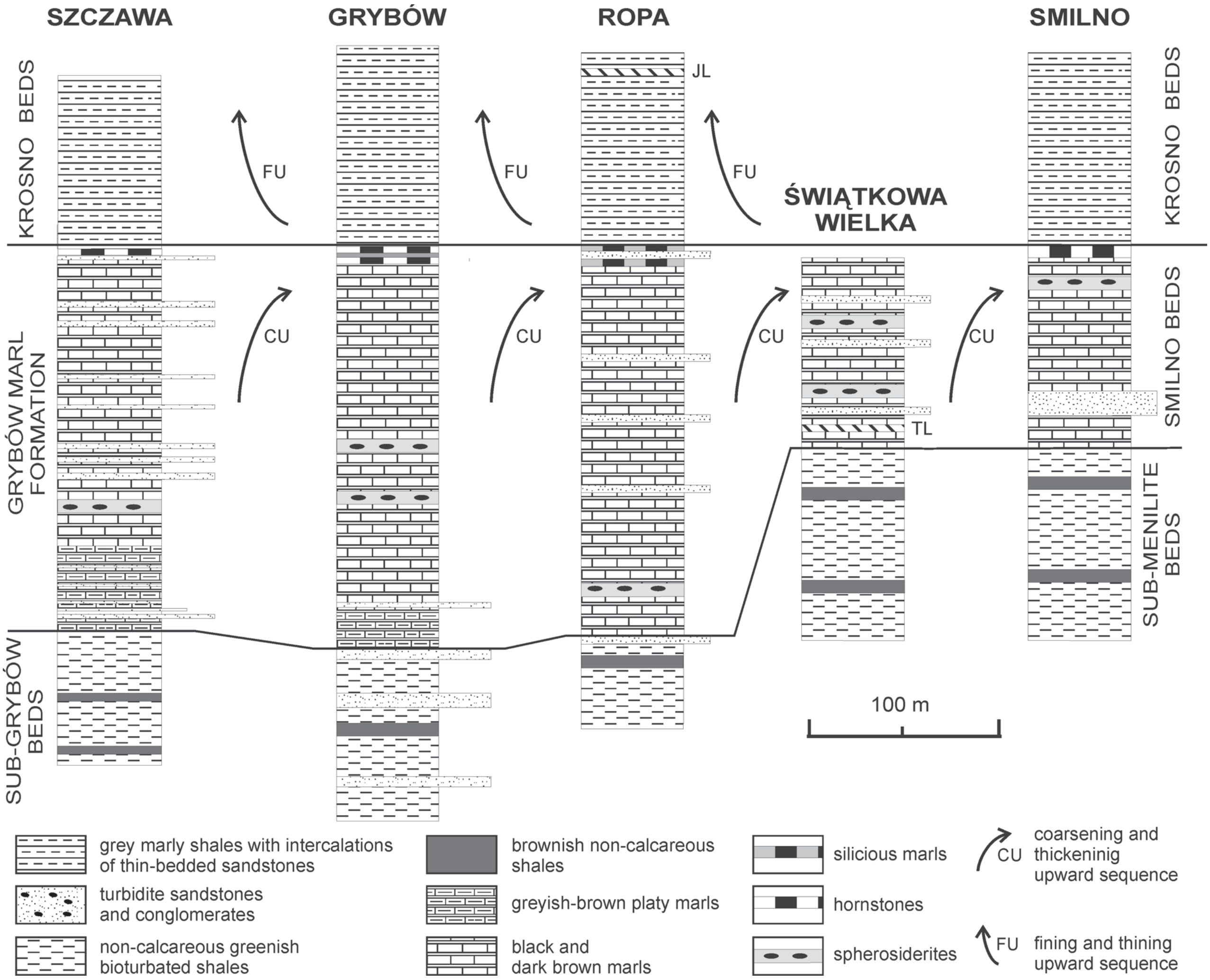

Fig. 11. Correlation logs of the Grybów succession. Profile of the Smilno Tectonic Window after Nemčok (1990) and Nemčok et al. (1990). Abreviations: **TL** — Tylawa Limestone, **JL** — Jasło Limestone.

Szczawa, Grybów and Ropa Tectonic Windows the thickness of the formation is up 200 m, while in the SWTW and Smilno Tectonic Windows (see Nemčok et al. 1990) the thickness oscillated around 100 m (Fig. 10). The lower boundary of the formation is transitional, while the upper boundary is represented by a horizon of silicites (horstones) (Fig. 11) with differnt thicknesses, varying from 10 cm in Szczawa up to 10 m on the Smilno site (see Nemčok et al. 1990). In the Ropa sites the horstone horizon is replaced by black siliceous marls (Oszczypko-Clowes 2008). The upper part of the succession is occupied by shally facies of the Krosno Beds at least 100 m thick. The Grybów succession correlate well with the succession of the Smilno Tectonic Window in Eastern Slovakia (Fig. 11, see also Nemčok 1990; Nemčok et al. 1990).

In the Smilno Beds, which can be regarded as the equivalent of the Grybów Marl Formation, Nemčok et al. (1990) described the thick-bedded "Kliwa" sandstones. This type of non-calcareous, quartz rich sandstone can be correlated with the same sandstones from the lower part of the GMF and Sub-Grybów Beds in the western part of the Światkowa Wielka section (Fig. 11).

The Rupelian sequences of the Grybów succession (Sub-Grybów and GMF) of the SWTW as well as the correlative deposits of the other tectonic window of the Polish sector of the Magura Nappe were deposited during the TA4 supercycle (Haq et al. 1988), resulting in a gradual rise of the relative sea level. The climatic and sequence-stratigraphy changes in the Central Carpathian Paleogene Basin during this supercycle have been defined by Soták et al. (2001). These changes can also be applicable to the depositional enviroments of the Menillite and Krosno Beds in the Outer Carpathian sedimentary area. The transgressive stage (TST) of the supercycle in the Grybów Sub-basin was probably marked by the deposition of menilite shales with green-interclations (Fig. 4A–D) of Sub-Grybów Beds and the basal portion of the GMF with the begining of the reticulofenestrides bloom. The highstand system tract (HST), with massive mud-rich marly megaturbiditic beds is typical for the main portion of GMF with the chert and siliceous marls at the top. The TB1 lowstand wedge (LSW) (see Soták et al. 2001) is marked by the beginning of the deposition of the shally Krosno Beds (Fig. 1) (NP24–NP25) zone.

The SWTW developed during multi-stage evolution (Fig. 10). This process was probably initiated during the latest Oligocene when the Magura Nappe was thrusted onto the Fore-Magura (Dukla and Grybów) sedimentary area. The overthrusting was probably realized under the submarine condition (see Oszczypko-Clowes & Oszczypko 2004). As a result the Magura Nappe, at least 2.5–3 km thick, loaded and sealed under compacted clayey-sandy deposits of the Grybów succession and shally upper Krosno Beds of the Dukla Nappe. This caused the appearance of an over pressured (see Oszczypko-Clowes & Oszczypko 2004; Bojanowski 2007b) zone along the contact between the Magura, Grybów and the Dukla Nappes. This zone, represented by the Krosno shally facies, was affected by a fracturing and frictional sliding and formation of tectono-sedimentary breccia. This type of breccia is also known from the Mszana Dolna Tectonic Window, as well as from deep boreholes Smilno 2 and Zborov 1 in the E Slovakia sector of the Magura Nappe (Leško et al. 1987). The successive Magura Nappe overthrusting during the Middle Miocene (Oszczypko 2006; Oszczypko-Clowes et al. 2009) against the Grybów and Dukla Nappes was formed as a classical contractional inter-thrust duplex between the Magura and Dukla Nappes (Mastella & Rubinkiewicz 1998) with several, refolded horses. In the SWTW the latest overthrust movement is documented by the retro-sharing of the Magura and Grybów Nappe of the northern limb of the window over the Magura Nappe of the southern none. This was probably connected with the exhumation of the upper Krosno Beds breccia from the top of the Dukla Nappe to the Krokowy Stream. This event probably took place during the latest post Sarmatian thrust movements in the Northern Outer Carpathian (see also Mastella & Rubinkiewicz 1998; Oszczypko-Clowes et al. 2009). The post nappe collapse of the Magura Nappe was accompanied by the development of the normal transversal faults (Figs. 2, 10A–B).

The present-day structure of the SWTW is related to the culmination of the basement of the Magura and Dukla stack of nappes.

To the east of the Dunajec River, the Magura Nappe is flatly overthrust upon its foreland (Fig. 1B). The undulation of the base of the Magura Nappe is well marked in the frontal thrust, forming characteristic "embayments" and "peninsulas" (Zuchiewicz & Oszczypko 2008). The first refers to the uplifted parts of the foreland and the second coincides with transversal depressions, but differences between the "embayments" and "peninsulas" do not exceed 250 m. Some 10–15 km south of the Magura frontal thrust, a belt of tectonic windows located upon a longitudinal basement elevation is to be found. This zone, 1–6 km wide, begins on the west in the Klęczany-Pisarzowa Window, and continues farther east through a half-window north of Nowy Sącz, and the Grybów-Ropa-Uście Gorlickie and Świątkowa and Kotoń Windows (Fig. 1). To the south of the Uście Gorlickie and Świątkowa Tectonic Windows, the base of the Magura Nappe rapidly slopes down to ca. 3300 m b.s.l. in Zborov-1 (ca. 2 km S of window) 4200 m b.s.l. in Smilno-1 (ca. 3 km W of window) well in Slovakia (Leško et al. 1987). This suggests that the Smilno Tectonic Window, like the Świątkowa Wielka one, is probably detached from its basement and embedded into the Magura thrust-sheets.

Conclusions

1. The studied section of the Świątkowa Wielka Tectonic Window is composed of the Dukla and Grybów Nappes. The Dukla Nappe is represented by shaly facies of the Krosno Beds, while the Sub-Grybów Beds and Grybów Marl Formation belong to the Grybów Sub-Nappe. We found the same tectonic sequence in the Mszana Dolna Tectonic Window.

2. In the Mszana Dolna and Świątkowa Wielka Tectonic Windows the age of the Krosno Beds of the Dukla Nappe has been determined as NP24.

3. The typical Oligocene sequence of the Grybów Sub-Nappe is composed of Sub-Grybów Beds, Grybów Marl Formation and Krosno Beds with the exception of the Świątkowa Wielka Tectonic Window.

4. The youngest deposits of the Grybów Sub-Nappe succession in the Świątkowa Wielka Tectonic Window belong to the Grybów Marl Formation and represent Zones NP23–NP24. The same results were obtained from the same deposits in the Mszana Dolna Tectonic Window. In the Grybów and Ropa Tectonic Windows the youngest age (Zone NP25) was determined in the Krosno Beds.

5. The abundance pattern and the species diversity of nannoplankton assemblages reflect temperate to coldish temperatures in the surface water of the Grybów Basin.

6. At the base of the Magura Nappe in the Mszana Dolna and Świątkowa Wielka Tectonic Windows the chaotic rocks of the breccia type were recognized.

7. In the case of the Świątkowa Wielka Tectonic Window these brecciated rocks probably represent a detached fragment of the Dukla Nappe, exhumed during the retro-thrust movement of the Magura Nappe towards the south. The amplitude of this ovethrust is at least 1.5 km.

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