STUDIA GEOLOGICA POLONICA

Vol. 124, Kraków 2005, pp. 353–369.

Methods and Applications in Micropalaeontology

Edited by J. Tyszka, M. Oliwkiewicz-Miklasińska, P. Gedl & M. A. Kaminski

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Calcareous nannoplankton from the Podhale Flysch (Oligocene–Miocene, Inner Carpathians, Poland)

(Figs 1–7)

Abstract. The presence of the Oligocene (upper Rupelian and Chattian)–Lower Miocene (Aquitanian) in the Podhale Flysch sediments is argued by the identification of calcareous nannoplankton zones: NP24, NP25 and NN1. The upper part of the Szaflary beds, the Zakopane beds and the lower part of the Chochołów beds belong to the NP24 Zone based on the occurrence of *Helicosphaera recta*, *Cyclicargolithus abisectus*, *Sphenolithus distentus*, *Reticulofenestra lockeri* and *Reticulofenestra ornata* in assemblages. The upper part of the Chochołów beds and the Brzegi beds belong to the NP25 Zone based on the presence of *Sphenolithus conicus* with the taxa listed above. The youngest Ostrysz beds contain *Helicosphaera scissura* and *Sphenolithus delphix*. These species are characteristic for the NN1 Zone (lowermost Miocene).

Key words: Inner Carpathian Palaeogene, Podhale Flysch, calcareous nannoplankton, biostratigraphy, Oligocene–Lower Miocene.

INTRODUCTION

Although the Podhale Flysch sediments were intensively studied from the micropalaeontological point of view (large and small foraminifera, calcareous nannoplankton, and dinocysts) the age of these sediments was not precisely defined. The individual groups of microfossils gave often equivocal results, especially in the case of calcareous nannoplankton. The aim of this work is to accurately determine the age of the sediments of the Podhale Flysch, based on nannofloral investigations, offering a calcareous nannoplankton biostratigraphical scheme.

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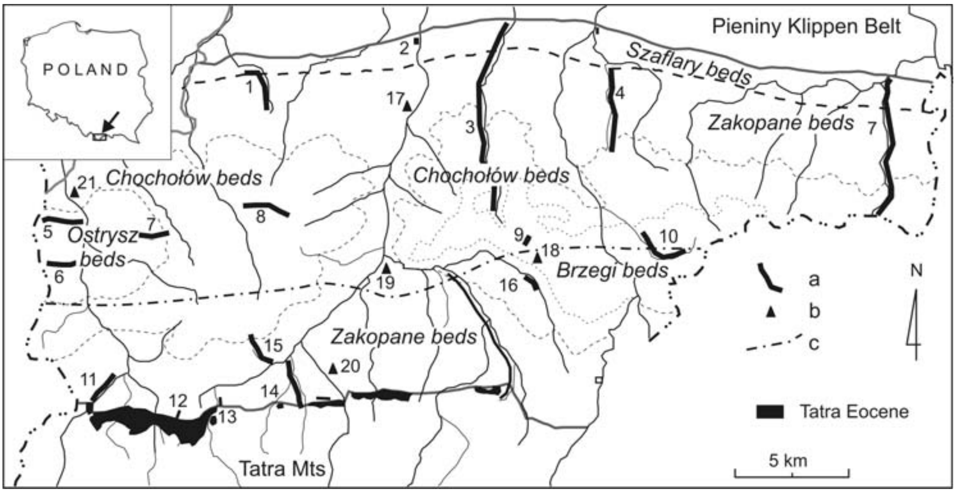


Fig. 1. Schematic location of the studied sections after Gedl (2000); geology after Małecka (1982) modified in the Tatra area by Birkenmajer (2000): a – surface outcrops: 1. Raczy Potok; 2. Szaflary; 3. Leśnica; 4. Trybski Potok; 5. Chrobaków Potok; 6. Garczkowski Potok; 7. Ostrysz; 8. Naglakowski Potok; 9. Bukowina Tatrzańska; 10. Jurgowczyk Potok; 11. Siwa Woda; 12. Staników Żleb; 13. Mała Łąka Valley; 14. Biały Potok stream; 15. Pająkówka; 16. Poroniec stream; b – boreholes: 17. Biały Dunajec PAN-1; 18. Bukowina Tatrzańska IG-1; 19. Poronin PAN-1; 20. Zakopane IG-1; 21. Chochołów PIG-1; c – southern limit of the Szaflary beds (after Kępińska, 1997)

MATERIAL AND METHODS

Calcareous nannoplankton was studied from a set of samples collected by P. Gedl and examined by him for dinocysts (Gedl, 2000). The location of the studied sections and boreholes is shown in Figure 1. A detailed description of the investigated profiles and sample positions were given by Gedl (2000). Additional samples were taken during field investigations by the author.

A total of 320 samples representing all lithostratigraphic units of the Podhale Flysch from 16 sections and from 6 boreholes were examined. The samples were prepared as smear slides according to the method described by Báldi-Beke (1984).

In the distribution charts (Figs 2–6), only selected nannofossils (the most common) are presented. The biostratigraphical scheme of the Podhale Flysch, based on calcareous nannoplankton zones is given in Figure 7.

GEOLOGICAL SETTING

The Podhale Palaeogene represents a part of the Central Carpathian Palaeogene deposits. It consists of Middle-Upper Eocene transgressive conglomerates and carbonate platform deposits, the so-called Tatra Eocene or the Nummulite Eocene, followed by the Oligocene flysch sediments of the Podhale Flysch (Roniewicz, 1979; Olszewska & Wieczorek, 1998; Olszewska, 1998; Gedl, 2000). Grey marls were

Epoch	Age	Zones	species / profiles	*Braarudosphaera bigelowii*	*Chiasmolithus oamaruensis*	*Clausicoccus subdistichus*	*Cyclicargolithus floridanus*	*Dictyococcites bisectus*	*Dictyococcites scrippsae*	*Discoaster barbadiensis*	*Discoaster saipanensis*	*Helicosphaera bramlettei*	*Helicosphaera compacta*	*Helicosphera intermedia*	*Helicosphaera recta*	*Isthmolithus recurvus*	*Lanternithus minutus*	*Pontosphaera latelliptica*	*Pontosphaera multipora*	*Reticulofenestra umbilica*	*Sphenolithus moriformis*	*Transversopontis pax*	*Zygrhablithus bijugatus*
OLIGOCENE	Chattian	NP24	Raczy Potok	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Rupelian	?	Szaflary				x	x			x		x			x	x			x	x	x	x
			Leśnica				x	x	x	x	x					x	x			x			x
			Trybski Potok	x			x	x			x									x			x

Fig. 2. Occurrence of selected calcareous nannoplankton from the Szaflary beds

Epoch	Age	Zones	species / profiles	*Braarudosphaera bigelowii*	*Clausicoccus subdistichus*	*Coccolithus formosus*	*Coccolithus pelagicus*	*Coronocyclus nitescens*	*Cyclicargolithus abisectus*	*Cyclicargolithus floridanus*	*Dictyococcites bisectus*	*Dictyococcites scrippsae*	*Discoaster deflandrei*	*Helicosphaera euphratis*	*Helicosphaera recta*	*Lanternithus minutus*	*Pontosphaera multipora*	*Reticulofenestra clatrata*	*Reticulofemnestra lockeri*	*Reticulofenestra ornata*	*Reticulofenestra umbilica*	*Sphenolithus distentus*	*Sphenolithus moriformis*	*Transversopontis fibula*
OLIGOCENE	Chattian	NP24	Raczy Potok	x	x	x	x		x	x	x	x	x		x	x	x		x	x	x	x	x	x
			Leśnica	x	x	x	x		x	x	x	x			x	x	x		x	x	x	x	x	
			Leśnica II	x		x	x		x	x	x					x			x		x			
			Trybski	x		x	x	x	x	x	x	x	x		x	x			x		x	x	x	
	Rupelian		Pająkówka	x	x	x	x		x	x	x		x		x	x	x		x		x	x	x	x
			Siwa Woda	x			x		x	x	x	x			x			x	x		x		x	x
			Staników Żl.	x		x	x		x	x	x	x		x		x	x		x		x		x	
			Mała Łąka	x		x	x		x	x	x	x					x		x		x			
			Biały Potok	x	x	x	x	x	x	x	x	x	x		x	x			x	x	x		x	

Fig. 3. Occurrence of selected calcareous nannoplankton from the Zakopane beds

found locally between the Nummulite Eocene deposits and the flysch (Sokołowski, 1973; Blaicher, 1973; Olszewska & Wieczorek, 1998).

The Podhale Flysch sediments, which overlie carbonate deposits, are more than 3000 m thick. Its succession has been informally divided by Gołąb (1959) and Watycha (1959, 1968). A comparison of these two divisions is presented by Roniewicz (1979). The Szaflary beds are the oldest deposits occurring in the northern part (peri-Klippen area) of the Podhale basin. They consist of coarse-grained flysch facies and brown bituminous shales, which resemble the menilitic shales of the Outer Carpathians. The Zakopane beds are the oldest flysch deposits in the southern part of the Podhale basin (peri-Tatra area). They are developed as dark-greyish shaly deposits with local dolomite interlayers. The Chochołów beds are regarded as normal flysch deposits with thick-bedded sandstones, submarine slumps and tuff layers (Roniewicz, 1979). In the eastern part of the Podhale basin Watycha (1959) distinguished a more shaly facies of the uppermost Chochołów beds: the Brzegi beds. The youngest sediments of the Podhale Flysch are the thick-bedded, sandy Ostrysz beds regarded by some authors (e.g., Roniewicz, 1979) as a part of the Chochołów beds. They are only known from the western part of the Podhale Basin (Gołąb, 1959).

RESULTS

Szaflary beds

Three nannofossil species predominate in the examined samples from this lithostratigraphic unit: *Coccolithus pelagicus*, *Dictyococcites bisectus* and *Reticulofenestra umbilica*. *Cyclicargolithus floridanus*, *Dictyococcites scrippsae*, *Discoaster barbadiensis*, *Discoaster saipanensis*, *Lanternithus minutus*, *Zygrhablithus bijugatus*, the Pontosphaeraceae and *Braarudosphaera bigelowii* are common as well. Fragments of Prinsiaceae (i.e., *Dictycoccites bisectus*, *Reticulofenestra umbilica*), Coccolithaceae (*Coccolithus pelagicus* and the genus *Chiasmolithus*) and Discoasteraceae are abundant. *Clausicoccus subdistichus*, *Helicosphaera bramlettei*, *H. compacta*, *H. recta*, *H.* cf. *reticulata*, *Transversopontis pax* occur in the upper part of the Szaflary beds in the Raczy Potok profile. *Isthmolithus recurvus* (a diagnostic species for the Upper Eocene) occurs very sporadically, and are usually found as fragments. Only single specimens of *Coccolithus formosus* have been observed.

In the borehole Biały Dunajec PAN-1 (the lower and middle part of the Szaflary beds) the calcareous nannoplankton assemblage is very poor. The species are damaged and scarce. The Eocene Discoasteraceae (i.e., *Discoaster barbadiensis, Discoaster saipanensis*) are not observed and *Coccolithus formosus* is missing. *Reticulofenestra umbilica* is noted only as a single specimens (usually damaged). Genera *Cribrocentrum* and *Dictyococcites* as well as the species *Reticulofenestra umbilica* are recorded as one specimen each in samples from the Poronin PAN-1 borehole.

Very frequent calcareous nannoplankton occurs in the lower part of the Szaflary beds in the Chochołów PIG-1 borehole. The assemblage contains *Braarudosphaera bigelowii*, *Coccolithus pelagicus*, *Cyclicargolithus floridanus*, *Dictyococcites bisectus*, *Pontosphaera multipora* and *Reticulofenestra umbilica* (Fig. 2).

Zakopane beds

The calcareous nannoplankton from the Zakopane beds has been studied in sections situated in the northern part of the Podhale basin (peri-Klippen area) and in the southern part (peri-Tatra area). Considerable differences in the frequency and preservation of nannofossils were observed between these two areas. In the peri-

Klippen area, the calcareous nannoplankton is abundant and diversified. *Coccolithus pelagicus*, *Dictyococcites bisectus* and *Cyclicargolithus floridanus* are the most common taxa in the examined samples. In all the samples from this area *Helicosphaera recta*, *Sphenolithus distentus*, *Cyclicargolithus abisectus*, *Reticulofenestra lockeri* and *Reticulofenestra ornata* have been identified. *Transversopontis fibula*, *T. obliquipons*, *T. pulcher*, *T. pulcheroides* and *Pontosphaera multipora* are common.

In the samples from the Zakopane beds of the peri-Tatra area the state of preservation of calcareous nannoplankton differs among the sections. Well preserved specimens are observed in the Siwa Woda profile, whereas poorly preserved ones occur in the more eastward profiles (i.e., Staników Żleb Gully, Mała Łąka, Biały Potok, Pająkówka). The Zakopane beds in the Siwa Woda profile contain the following stratigraphically important Oligocene species: *Cyclicargolithus abisectus*, *Helicosphaera recta*, *Reticulofenestra clatrata* and *R. lockeri*. *Braarudosphaera bigelowii*, *Coccolithus pelagicus*, *Cyclicargolithus floridanus*, *Dictyococcites bisectus*, *Transversopontis fibula* and *Reticulofenestra umbilica* dominate in the nannofloral assemblages. The lower part (according to Watycha, 1959) of the Zakopane beds was sampled in the Biały Potok profile. The same species as those mentioned above have been identified in this section. In the upper part of this profile, an increase in coccolith number has been observed, the assemblage is more diversified, but the specimens are not well preserved. Almost ninety percent of the assemblage is found as fragments. A similar assemblage (but without *Helicosphaera recta*) is observed in other profiles of the Zakopane beds in the peri-Tatra area. In all the samples, representatives of Pontosphaeraceae (mostly *Pontosphaera multipora* and sporadically *Transversopontis fibula*) occur, but in the Mała Łąka profile *Braarudosphaera bigelowii* is more common than the Pontosphaeraceae, although they occur in fragments.

In the Chochołów PIG-1 borehole in the upper part of the Zakopane beds *Cyclicargolithus abisectus* and *Reticulofenestra ornata* are the only Oligocene taxa present. In the Bukowina Tatrzańska IG-1 borehole *Helicosphaera recta* occurs, while the above two mentioned species are missing (Fig. 3).

Chochołów beds

The calcareous nannoplankton in the examined samples from the Chochołów beds of the peri-Klippen area is rare and poorly preserved. The Pontosphaeraceae occur sporadically, while the Sphenolithaceae (small-sized specimens), the Eocene species of the genus *Discoaster* and the Prinsiaceae (the genus *Cyclicargolithus*) are more common. In the samples from the Leśnica stream *Braarudosphaera bigelowii, Cyclicargolithus abisectus, Cyclicargolithus floridanus*, *Discoaster deflandrei*, *Helicosphaera recta*, *Transversopontis fibula*, *Reticulofenestra lockeri* and *Reticulofenestra ornata* have been observed. In the samples from the Trybski stream profile no typical Oligocene species have been found. Only long-ranging *Dictyococcites bisectus* and *Zygrhablithus bijugatus* occur frequently.

Epoch	Age	Zones	species / profiles	*Braarudosphaera bigelowii*	*Clausicoccus subdistichus*	*Coccolithus formosus*	*Coccolithus pelagicus*	*Cyclicargolithus abisectus*	*Cyclicargolithus floridanus*	*Dictyococcites bisectus*	*Dictyococcites scrippsae*	*Helicosphaera compacta*	*Helicosphaera recta*	*Lanternithus minutus*	*Pontosphaera enormis*	*Pontosphaera latelliptica*	*Pontosphaera multipora*	*Reticulofenestra lockeri*	*Reticulofenestra ornata*	*Reticulofenestra umbilica*	*Sphenolithus ciperoensis*	*Sphenolithus conicus*	*Sphenolithus distentus*	*Sphenolithus moriformis*	*Transversopontis fibula*	*Zygrhablithus bijugatus*
OLIGOCENE	Chattian	NP25	Bukow.T.			x	x	x	x	x	x		x	x			x	x	x	x	x	x		x		x
			Naglak.	x		x	x	x	x	x			x	x	x	x	x	x		x				x	x	x
		NP24	Jurgow.	x		x	x	x	x	x		x		x		x				x						x
			Leśnica	x	x	x	x	x	x	x	x	x	x	x			x	x	x	x			x	x	x	x
	Rupelian		Leśnica II	x	x		x	x	x	x				x		x		x	x	x				x	x	x
			Trybski		x	x	x	x	x	x				x						x				x		x
			Pająkówka	x		x	x	x	x	x			x	x			x	x		x				x		x

Fig. 4. Occurrence of selected calcareous nannoplankton from the Chochołów beds and Brzegi beds

The calcareous nannoplankton assemblage from the Chochołów beds of the peri-Tatra area consists of *Braarudosphaera bigelowii*, *Cyclicargolithus abisectus*, *C. floridanus*, *Helicosphaera intermedia*, *H. recta*, *Reticulofenestra lockeri* and *R. ornata*. Fragments of the genera *Discoaster* and *Pontosphaera* are frequently found.

In the samples from the Jurgowczyk and Bukowina Tatrzańska profiles (the uppermost part of the Chochołów beds = the Brzegi beds) *Coccolithus pelagicus*, *Cyclicargolithus floridanus*, *Dictyococcites bisectus*, *Reticulofenestra umbilica* and *Zygrhablithus bijugatus* occur. In the Bukowina Tatrzańska profile *Helicosphaera recta*, *H. reticulata*, *Reticulofenestra lockeri, Sphenolithus ciperoensis* and *Sphenolithus conicus* have also been found (Fig. 4).

The Ostrysz beds

Calcareous nannoplankton from the Ostrysz beds is relatively abundant and diversified but the state of preservation and the amount of recycled specimens hinder specific identification. The majority of nannofossils known from older lithostratigraphic units of the Podhale Flysch occurs also in this unit. In almost all the samples *Pontosphaera desueta* and *P. enormis* occur. *Pontosphaera multipora*, *P. latelliptica* (more common than the first species) and *Braarudosphaera bigelowii* are very frequent in the examined samples. The Helicosphaeraceae are represented by *Helicosphaera euphratis*, *H. intermedia*, *H. obliqua*, *H. perch-nielsenae*, *H. recta* and *H. scissura*. Besides *Sphenolithus moriformis* (the most common representative of the family Sphenolithaceae in the Podhale Flysch) *S. delphix* is observed here (Fig. 5).

Preservation and the problem of recycling

The studied calcareous nannoplankton from the Podhale Flysch is abundant, but due to the commonly poor state of preservation many species were excluded from

Epoch	Age	Zones	species / profiles	Braarudosphaera bigelowii	Coccolithus pelagicus	Cyclicargolithus abisectus	C. floridanus	Dictyococcites bisectus	Discoaster deflandrei	Helicosphaera bramlettei	H. euphratis	H. intermedia	H. obliqua	H. perch-nielsenae	H. recta	H. scissura	Pontosphaera desueta	P. enormis	P. latelliptica	P. multipora	P. rothii	Reticulofenestra lockeri	R. ornata	Sphenolithus conicus	S. delphix	S. distentus	S. moriformis	Transversopontis fibula	Zygrhabdolithus bijugatus
MIOCENE	Aquitanian	NN1	Ostrysz/PG	x	x	x	x	x	x	x					x	x			x	x				x			x	x	x
			Ostrysz/MG	x	x	x	x	x		x	x	x	x	x	x	x	x		x	x		x	x		x		x	x	x
			Chrobaków		x	x	x	x	x							x	x	x	x	x		x	x			x	x	x	x
OLIGO-CENE?	?	?	Garczkowski	x	x	x	x	x		x					x				x	x	x						x		x

Fig. 5. Occurrence of selected calcareous nannoplankton from the Ostrysz beds

the identification procedure. The nannofossil assemblages from all the investigated lithostratigraphic units are dominated by temperate-, cold water and long-ranging species. In such cases, it is not possible to distinguish the recycled species from autochthonous ones, especially if they are badly preserved.

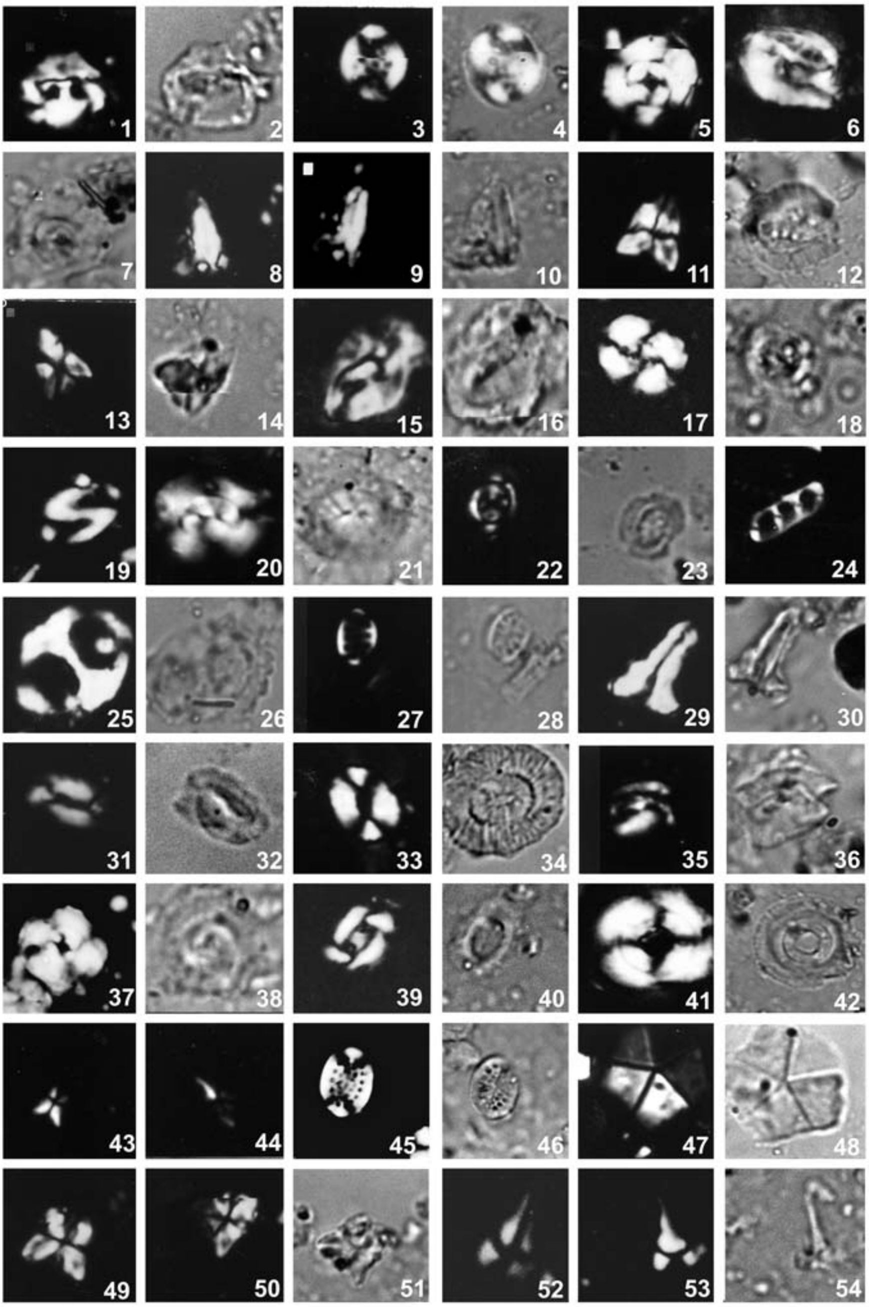
The major problem of preservation refers to mechanical deformation. However, calcification and corrosion play a more significant role in the case of nannofossils from the Zakopane beds of the peri-Tatra area. In several cases, the calcareous nannoplankton assemblage from the same sample contains well preserved and damaged specimens where the autochthonous taxa are much worse preserved than the recycled ones. Thus, the state of preservation is not a discriminating factor for distinguishing between recycled and *in situ* species (Fig. 6).

The Eocene species are the most frequent among the recycled taxa. The Palaeocene–Eocene and Cretaceous species (mostly identified in the Chochołów and the Ostrysz beds) occur very sporadically. However, it is often difficult to determine whether long-ranging species are *in situ* or they are recycled.

BIOSTRATIGRAPHY

Calcareous nannoplankton biostratigraphy of Oligocene and Lower Miocene

The most frequently used Palaeogene and Neogene calcareous nannoplankton zonations are Martini's scheme (1971) with later modification (Martini & Müller, 1986) and Bukry's scheme (1971, 1973) modified by Okada & Bukry (1980). The Oligocene nannofossil zonations of the above-mentioned authors are considerably based on sphenoliths (typical warm water species), which are very rare or absent in high latitudes. Because of their often small dimensions their identification is often impossible (especially in badly preserved material). Therefore, difficulties arise when using these species as diagnostic taxa for the identification of the nannofossil zones in Oligocene deposits of higher latitudes, particularly in flysch sediments. Investigations of calcareous nannoplankton from Oligocene sections in northern Europe (Müller, 1970; Benedek & Müller, 1974) have shown that *Cyclicargolithus abisectus* and *Helicosphaera recta* have their lowest occurrences approximately at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the boundary of the *Sphenolithus predistentus*/*Sphenolithus distentus* zones (NP23/24) of the standard zonation (Martini, 1971; Martini & Müller, 1986). The nannoplankton assemblage of this zone is comparable with those of the North Atlantic and very similar to the assemblage of the Upper Rupelian from northern Europe (Müller, 1970). The top of the *Sphenolithus distentus* Zone is characterized by the lowest occurrence (LO) of *Pontosphaera* (*Discolithina*) *enormis* (Müller, 1976; Benedek & Müller, 1974; Martini & Müller, 1986). The nannoplankton assemblage of this zone is comparable with those of the North Atlantic and very similar to the assemblage from the upper Rupelian of northern Europe (Müller, 1970). According to several authors (Báldi–Beke, 1981; Melinte, 1995; Bizon & Müller, 1979; Biolzi *et al*., 1981), the LO of *Sphenolithus conicus* could be used as a substitute for the LO of *Pontosphaera enormis*.

The NP25 Nannofossil Zone was divided into two Subzones: NP25a and NP25b (Melinte, 1995, Melinte *in*: Rusu *et al.*, 1996). The lower boundary of the NP25a Subzone is defined by the highest occurrence (HO) of *Sphenolithus distentus* and/or by the LO of *Pontosphaera enormis*. The upper boundary of this Subzone (and the lower boundary of the NP25b Subzone) is defined based on the LO of *Helicosphaera paleocarteri* and/or the LO of *Triquetrorhabdulus carinatus*. The upper boundary of this Subzone (i.e., the lower boundary of following NN1 Zone) is marked by the LO of *Helicosphaera scissura* and/or by the HO of *Dictyococcites bisectus*. In Martini's scheme, the lower boundary of the NN1 Zone is based on the

Fig. 6. Calcareous nannoplankton from the Podhale Flysch. **1, 2** – *Helicosphaera recta*, 1: CN, 2: NL, Szb, Raczy Potok; **3, 4** – *Pontosphaera enormis*, 3: CN, 4: NL, Chb, Naglakowski Potok; **5** – *Cyclicargolithus abisectus*, CN, Zb, Raczy Potok; **6** – *Helicosphaera reticulata*, CN, Ob, Ostrysz; **7** – *Cyclicargolithus abisectus*, NL, Zb, Raczy P.; **8, 9** – *Sphenolithus ciperoensis*, 8: CN-0°, 9: CN-45°, Chb, Bukowina Tatrz.; **10** – *Sphenolithus ciperoensis*, NL-0°,Chb, Bukowina Tatrz.; **11** – *Sphenolithus conicus*, CN-0°, Chb, Bukowina Tatrz.; **12** – *Helicosphaera reticulata*, NL, Ob Ostrysz; **13, 14** – *Sphenolithus conicus*, 13: CN-45°, 14: CN-0°, Chb, Bukowina Tatrz.; **15, 16** – *Helicosphaera compacta*, 15: CN, 16: NL, Szb, Raczy P.; **17, 18** – *Reticulofenestra ornata*, 17: CN, 18: NL, Zb, Biały stream; **19** – *Transversopontis obliquipons*, CN), Szb, Trybski Potok**; 20, 21** – *Dictyococcites bisectus*, 20: CN, 21: NL, Szb, Raczy P.; **22, 23** – *Clausicoccus subdistichus*, 22: CN, 23: NL, Szb, Raczy P.; **24** – *Isthmolithus recurvus,* NL, Chb, Trybski P.; **25** – *Transversopontis fibula*, CN, Zb, Siwa Woda; **26** – *Transversopontis fibula,* NL, Zb, Siwa Woda; **27** – *Pontosphaera desueta*, CN, Ob, Ostrysz; **28** – *Pontosphaera desueta*, NL, Ob, Ostrysz; **29** – *Zygrhablithus bijugatus*, CN, Szb, Leśnica; **30** – *Zygrhablithus bijugatus,* NL, Szb, Leśnica; **31** – *Helicosphaera scissura*, CN, Ob, Ostrysz; **32** – *Helicosphaera scissura* NL, Ob, Ostrysz; **33, 34** – *Coccolithus pelagicus*, 33: CN, 34: NL, Szb, Raczy P.; **35, 36** – *Helicosphaera perch-nielseniae*, 35: CN, 36: NL, Ob, Ostrysz; **37, 38** – *Cyclicargolithus floridanus,* 37: CN, 38: NL, Chb, Trybski P.); **39, 40** – *Reticulofenestra lockeri*, 39: CN, 40: NL, Zb, Siwa Woda); **41, 42** – *Coccolithus formosus*, 41: CN, 42: NL, Szb, Raczy P.; **43, 44** – *Sphenolithus delphix*, 43: CN-0°, 44: CN-45°, Ob, Ostrysz; **45, 46** – *Pontosphaera multipora*, 45: CN, 46: NL, Zb, Raczy P.; **47, 48** – *Braarudosphaera bigelowii*, 47: CN, 48: NL, Szb, Leśnica; **49** – *Sphenolithus moriformis*, CN-0°, Szb (Raczy P.); **50, 51** – *Sphenolithus moriformis*, 50: CN-45°, 51: NL-45°, Szb, Raczy P.; **52, 53** – *Sphenolithus distentus*, 52: CN-0°, 53: CN-45°, Zb Biały Potok; **54** – *Sphenolithus distentus*, NL-45°, Zb, Biały Potok. CN – crossed nicols; NL – parallel nicols; magnification of all specimens ×1500; Chb – Chochołów beds, Ob – Ostrysz beds, Szb – Szaflary beds, Zb – Zakopane beds

HO of *Helicosphaera recta* and/ or the HO of *Sphenolithus ciperoensis*. However, the HO of *Helicosphaera recta* is noticed in the NN1 Zone. According to Biolzi *et al*. (1981), the boundary between the NP25/NN1 Nannofossil zones could be recognized based on the synchronous HOs of *Dictyococcites bisectus*, *Sphenolithus ciperoensis* and *Zygrhablithus bijugatus*. These highest occurrences are also synchronous events with the LO of *Triquetrorhabdulus carinatus* and correspond to the base of the NN1 Zone (Martini, 1971). Despite this, Martini (1971) reports the occurrence of *Triquetrorhabdulus carinatus* also in the NP25 Zone and even in the upper part of the NP24 Zone. In poorly preserved material, it is difficult to differentiate *Triquetrorhabdulus carinatus* from other normal elongated calcite elements.

The HO of *Dictyococcites bisectus* coincides with the LOs of *Helicosphaera scissura* and *Sphenolithus compactus* (Melinte *in*: Rusu *et al.*, 1996). This event is used as a criterion to mark the Oligocene–Miocene boundary. According to Aubry & Villa (1996) the LO of *Sphenolithus delphix* is the only event that marks the Oligocene–Miocene boundary. However, Fornaciari (*in*: Fornaciari *et al.*, 1990) noted that this species is restricted to the upper part of the Lower Miocene Subzone CN1c (NN2), where it occurs very frequently.

The lowest occurrence of *Helicosphaera scissura* seems to be the most suitable nannofossil event to mark the lower boundary of the NN1 Zone. This species was described from the menilite-Krosno beds (Polish Flysch Carpathians) by Garecka (1997); Koszarski *et al.* (1995) and Ślęzak *et al.* (1995). The Romanian stratigraphers (Melinte, 1995; Melinte *in*: Rusu *et al.*, 1996) marked the lower boundary of the NN1 Zone based on the LO of *Helicosphaera scissura* (and *Helicosphaera mediterranea*). In the studied material, *Helicosphaera mediterranea* is missing, while in the menilite-Krosno beds of the Polish Outer Carpathians this species occurs together with *Helicosphaera ampliaperta* in the NN2 Zone (Koszarski *et al.*, 1995; Ślęzak *et al.*, 1995; Garecka, 1997; Garecka & Olszewska, 1998).

Age of the Podhale Flysch based on calcareous nannoplankton

Szaflary beds. The occurrence of *Helicosphaera recta* (only) in this lithostratigraphic unit indicates that it represents the NP24 Zone (*Sphenolithus distentus* Zone) – probably its lower part. However, it is not possible to determine the age of the lower part of the Szaflary beds. In the studied samples, the recycled specimens dominate, the diagnostic species are missing, and the species that have their highest occurrences in the Lower Oligocene are absent or occur as single, damaged forms. It may suggest that the age of this part of the Szaflary beds is not older than early Rupelian (?NP23 Zone or the upper part of ?NP22 Zone). Thus, the age of the Szaflary beds based on calcareous nannoplankton is Early Oligocene (middle Rupelian) (Fig. 7).

Zakopane beds. The calcareous nannoplankton from the Zakopane beds represents the NP24 Zone. This is based on the occurrence of *Cyclicargolithus abisectus*, *Helicosphaera recta*, *Sphenolithus distentus* and other species, such as: *Reticulo-*

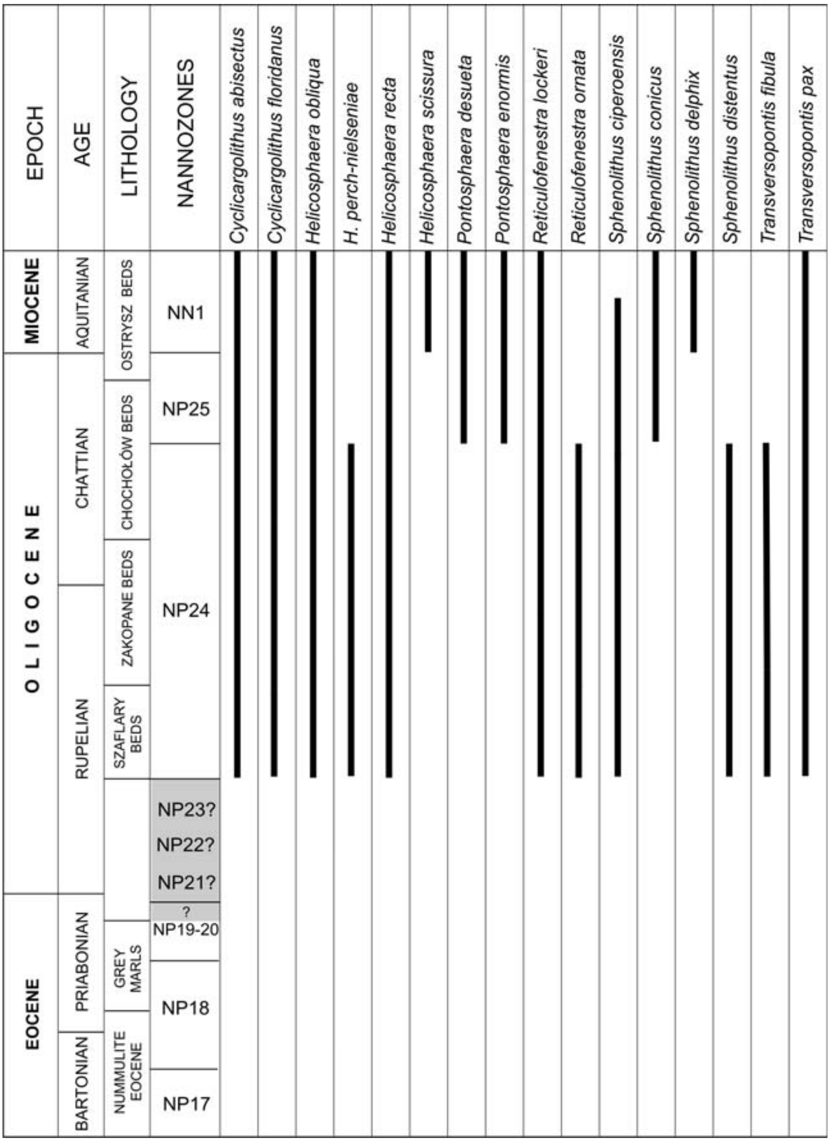

Fig. 7. Biostratigraphic scheme of the Podhale Flysch based on calcareous nannoplankton

fenestra lockeri, R. ornata, and *Transversopontis fibula*. Therefore, a late Rupelian–early Chattian age of this lithostratigraphic unit may be suggested (Fig. 7).

Chochołów beds. The same assemblage as in the Zakopane beds has been found in the lower part of the Chochołów beds, suggesting its correlation with the NP24 Zone. The calcareous nannoplankton from the upper part of the Chochołów beds and the Brzegi beds is assigned to the NP25 Zone (*Sphenolithus ciperoensis* Zone). In the upper part of the Chochołów beds exposed in the Naglakowski Potok profile, *Pontosphaera enormis*, *Cyclicargolithus abisectus*, *Helicosphaera recta* and *Reticulofenestra lockeri* have been found, whereas *Sphenolithus distentus*, the highest occurrence of which marks the upper boundary of NP24 Zone, has not been found. Besides the above mentioned species, *Sphenolithus conicus* (typical for the NP25 Zone) and *Sphenolithus ciperoensis* occur in the Brzegi beds. Thus, a late Rupelian–Chattian age for the Chochołów beds (Chattian age of the Brzegi beds) may be concluded (Fig. 7).

Ostrysz beds. The calcareous nannoplankton from the Ostrysz beds can be assigned to the NN1 Zone (*Triquetrorhabdulus cariantus* Zone). This is based on the occurrence of *Helicosphaera scissura* and *Sphenolithus delphix* in this lithostratigraphic unit. Its age can be suggested as the Early Miocene (Fig. 7). The calcareous nannoplankton assemblage from the Garczkowski Potok profile, which presumably represent the lower part of this lithostratigraphical unit, represents probably the NP25 Zone (Figs 5, 7).

Discussion

The hitherto performed studies of the calcareous nannoplankton from the Podhale Flysch sediments were disputable due to contradictory ages assigned to the same lithostratigraphic units. Moreover, the comparison between nannoplankton and other groups of microfossils gave ambiguous findings as well. The results obtained and presented in this contribution have not confirmed Dudziak's (e.g., 1983, 1984, 1986, 1993) findings of the Late Eocene and Early Oligocene age of the Zakopane beds and the Early Oligocene age of the Chochołów and Ostrysz beds. In his investigations, Dudziak emphasized the poor state of preservation of the calcareous nannoplankton in the samples and the fact that long-ranging and recycled species are dominant. All these outcomes make the age determination very difficult (or often impossible), which is also experienced in this study.

Smagowicz (*in*: Chowaniec *et al.*, 1992; Poprawa *et al.*, 1992) presented a different interpretation of the age of the Podhale Flysch and according to her, the lower part of the Szaflary beds may represent the Upper Eocene (NP19/20 Zone). In the samples from the field outcrops, which according to Kulka (*in*: Chowaniec *et al.*, 1990) represent the Szaflary beds, Smagowicz (*in*: Chowaniec *et al.*, 1990) noted the occurrence of *Sphenolithus distentus* and *Sphenolithus ciperoensis* and suggested an Oligocene age (late Rupelian–early Chattian?) for the Szaflary beds. These findings support the age of these beds presented in this study. According to Smagowicz (*in:* Chowaniec *et al.,* 1990; Chowaniec *et al.*, 1992), the Zakopane beds comprise a very wide interval from the Upper Eocene to the Upper Oligocene (?). Based on the study of the Bukowina Tatrzańska IG-1 borehole, the Zakopane beds are Oligocene in age (Lower/Middle Oligocene). An even younger calcareous nannoplankton assemblage was found by Smagowicz (*in:* Chowaniec *et al.*, 1990) in the upper part of the Zakopane beds from the Furmanowa IG-1 borehole. It contains *Helicosphaera ampliaperta*, *H. recta*, *Sphenolithus distentus*, *S.* cf. *heteromorphus*, *S. ciperoensis*, *S. conicus*, *Reticulofenestra lockeri*, *R.* cf. *abisecta* and *R.*

minuta. The lowest occurrence of *Helicosphaera ampliaperta* marks the lower boundary of the NN2 Zone (Perch-Nielsen, 1985; Koszarski *et al.*, 1995; Ślęzak *et al.*, 1995; Garecka, 1997; Garecka & Olszewska, 1998) whereas *Sphenolithus heteromorphus* occurs in the NN4 Zone (e.g. Perch-Nielsen, 1985). This assemblage suggests an Early Miocene age for the upper part of the Zakopane beds. The present investigation shows that the entire lithostratigraphical unit of the Zakopane beds belongs to the NP24 Zone. Based on calcareous nannoplankton (present paper) the Chochołów beds and the Brzegi beds can be assigned to the NP24 and NP25 zones. To some extent, these results confirm the findings of Smagowicz (Smagowicz, *in:* Chowaniec *et al.*, 1992; Poprawa *et al.*, 1992) who assigned the Chochołów beds to the lower part of the Upper Oligocene.

In the samples of the Biely Potok Formation (= Ostrysz beds) in Slovakia *Triquetrorhabdulus carinatus*, *Helicosphaera scissura*, *H. kamptneri*, *H.* cf. *ampliaperta*, *Reticulofenestra* cf. *pseudoumbilica, Sphenolithus* cf. *conicus*, *S.* cf. *delphix*, *S.* cf. *calyculus*, *S. dissimilis, S. capricornutus* have been identified (Janočko *et al.*, 1998; Starek *et al.*, 2000).

According to Gedl (e.g. 2000) the Podhale Flysch is Oligocene in age (from mid-Rupelian to Late Chattian). The dinocyst assemblage from the Ostrysz beds suggests their late Chattian age whereas no dinocysts typical for latest Chattian and Early Miocene have been found there. The dinocyst assemblages from the Chochołów and the Ostrysz beds resemble the dinocysts assemblages from the Krosno beds, but the latter are definitely poorer (in comparison with the Ostrysz beds especially) and less differentiated. Similar analogies can be observed in the case of calcareous nannoplankton. The assemblages from the menilite-Krosno beds are very poor (even scarce) and often absent; especially within the Oligocene–Miocene transitional interval.

The smaller foraminifera (e.g., Olszewska *in*: Chowaniec *et al.*, 1990; Olszewska & Wieczorek, 1998) indicate that the Szaflary beds are not older than latest Eocene (late Priabonian). The Zakopane beds contain foraminiferal assemblages which are characteristic for the Early Oligocene, and show similarities to assemblages from the lower Krosno beds in the Polish Outer Carpathians and to the assemblages of the *Globigerina postcretacea* Zone of the Central Carpathian Palaeogene in Slovakia (Blaicher, 1973; Olszewska *in*: Chowaniec *et al.*, 1990; Olszewska *in*: Chowaniec *et al.*, 1992; Olszewska & Wieczorek, 1998).

CONCLUSION

1. A total of 320 samples representing all lithostratigtaphic units of the Podhale Flysch from 16 sections and 6 boreholes have been examined for calcareous nannoplankton.

2. The presence of the Oligocene (upper Rupelian and Chattian)–Lower Miocene (Aquitanian) in the Podhale Flysch sediments is argued by the identification of the calcareous nannoplankton zones: NP24, NP25 and NN1. The upper part of the Szaflary beds, the Zakopane beds and the lower part of the Chochołów beds belong

to the NP24 Zone. The upper part of the Chochołów beds (and the Brzegi beds) belong to the NP25 Zone. The youngest Ostrysz beds represents the NN1 Zone.

3. The calcareous nannoplankton assemblages from the Chochołów and Ostrysz beds resemble the nannofossil assemblages from the Krosno beds. The latter (in comparison with the Ostrysz beds especially) are very poor (even scarce) and often absent.

Acknowledgements

I would like to thank Dr M. C. Melinte for critically reviewing the manuscript and for helpful comments. I would like to thank Dr P. Gedl for providing the samples for this study, and for discussion and critical reading of the manuscript. Special thanks are due to M.Sc. T. Mrozek (Polish Geological Institute, Carpathian Branch, Kraków) for linguistics correction and critical remarks. I also thank Dr R. Kopciowski (Polish Geological Institute, Carpathian Branch, Kraków) for his help during fieldworks.

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APPENDIX

Alphabetical listing of calcareous nannoplankton found in the Podhale Flysch.

Braarudosphaera bigelowii (Graan & Braarud) Deflandre
Chiasmolithus eograndis Perch-Nielsen
Chiasmolithus expansus (Bramlette & Sullivan) Gartner
Chiasmolithus gigas (Bramlette & Sullivan) Radomski
Chiasmolithus grandis (Bramlette & Riedel) Radomski
Chiasmolithus modestus Perch-Nielsen
Chiasmolithus oamaruensis (Deflandre) Hay, Mohler & Wade
Clausicoccus subdistichus (Roth & Hay) Prins
Coronocyclus nitesens (Kamptner) Bramlette& Wilcoxon
Cribrocentrum reticulatum (Gartner& Smith) Perch-Nielsen
Cyclicargolithus abisectus (Müller) Wise
Cyclicargolithus floridanus (Roth & Hay)Bukry
Cyclicargolithus luminis Sullivan
Cyclicargolithus marismontium Black
Coccolithus formosus (Kamptner) Haq
Coccolithus pelagicus (Wallich) Schiller
Dictyococcites bisectus (Hay, Mohler & Wade) Bukry & Percival
Dictyococcites callidus Perch-Nielsen
Dictyococcites daviesii (Hay) Perch-Nielsen
Dictyococcites heslandii (Hay) Haq & Lohmann
Dictyococcites scrippsae Bukry & Percival
Discoaster barbadiensis Tan
Discoaster bifax Bukry
Discoaster binodosus Martini
Discoaster deflandrei Bramlette & Riedel
Discoaster diastypus Bramlette & Sullivan
Discoaster distinctus Martini
Discoaster elegans Bramlette & Sullivan
Discoaster kuepperi Stradner
Discoaster lodoensis Bramlette & Riedel
Discoaster multiradiatus Bramlette & Riedel

Discoaster saipanensis Bramlette & Riedel
Discoaster tanii Bramlette & Riedel
Discoaster tanii nodifer Bramlette & Riedel
Ericsonia fenestrata (Deflandre & Fert) Strander
Helicosphaera bramlettei Müller
Helicosphaera compacta Bramlette & Wilcoxon
Helicosphaera euphratis Haq
Helicosphaera heezenii Bukry
Helicosphaera intermedia Martini
Helicosphaera lophota Bramlette & Sullivan
Helicosphaera obliqua Bramlette & Wilcoxon
Helicosphaera perch-nielseniae Haq
Helicosphaera recta Haq
Helicosphaera reticulata Bramlette & Wilcoxon
Helicosphaera scissura Miller
Helicosphaera seminulum Bramlette & Sullivan
Isthmolithus recurvus Deflandre
Lanternithus minutus Stradner
Markalius inversus (Deflandre) Bramlette & Martini
Neococcolithes dubius (Deflandre) Black
Pontosphaera desueta (Müller) Perch-Nielsen
Pontosphaera enormis (Locker) Perch-Nielsen
Pontosphaera latelliptica Báldi-Beke & Báldi, Perch-Nielsen
Pontosphaera multipora (Kamptner) Roth
Pontosphaera punctosa (Bramlette & Sullivan) Perch-Nielsen
Pontospahera rothii Haq
Reticulofenestra clatrata Müller
Reticulofenestra dictyoda (Deflandre) Stradner
Reticulofenestra hillae Bukry & Perciv
Reticulofenestra lockeri Müller
Reticulofenestra ornata Müller
Reticulofenestra umbilica (Levin) Martini & Ritzkowski
Sphenolithus ciperoensis Bramlette & Wilcoxon
Sphenolithus conicus Bukry
Sphenolithus conspicuus Martini
Sphenolithus delphix Bukry
Sphenolithus distentus (Martini) Bramlette & Wilcoxon
Sphenolithus editus Perch-Nielsen
Sphenolithus moriformis (Brönnimann & Stradner) Bramlette & Wilcoxon
Sphenolithus predistentus Bramlette & Wilcoxon
Sphenolithus pseudoradians Bramlette & Wilcoxon
Sphenolithus radians Deflandre
Sphenolithus spiniger Bukry
Thoracosphaera saxea Stradner
Toweius eminens (Bramlette & Sullivan) Perch-Nielsen
Toweius gammation (Bramlette & Sullivan) Romein
Transversopontis fibula Gheta
Transversopontis obliquipons (Deflandre) Hay, Mohler & Wade
Transversopontis pax Stradner & Seifert
Transversopontis pulcher (Deflandre) Perch-Nielsen
Transversopontis pulcheroides (Sullivan) Báldi-Beke
Tribrachiatus orthostylus Shamrai
Zygrhablithus bijugatus (Deflandre) Deflandre