The Paleogene of the Podhale Basin (Polish Inner Carpathians) — micropaleontological perspective

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Recent investigations of the calcareous nannoplankton, small foraminifera and dinoflagellata has thrown additional light on the age and environment of deposition of the Paleogene deposits of the Podhale Basin. Large and small foraminifera indicate for the Nummulite Eocene Bartonian–early Priabonian age and accumulation in different ernvironments of the shallow carbonate platform. Planktic foraminifera from the uppermost slope grey marls indicate P15–P16 zone while calcareous nannoplankton data are inconsistent indicating NP16–NP17 or 19/20 coccolith zones. The turbidite deposits of the Podhale flysch accumulated predominately during the Oligocene.

Key words: *new data, Paleogene, sedimentary basins, microfossils, stratigraphy, paleoenvironment, Podhale, Polish Carpathians*

Introduction

The Paleogene deposits of the Polish part of Inner Carpathians (the Tatra Mts and the Podhale Basin) represent four distinct facies: the pre-Late Lutetian basal conglomerates, the Bartonian-earliest Priabonian sublittoral nummulitic limestones, the Priabonian hemipelagic marls with planktic foraminifera, and the Oligocene turbidite clastics. Foraminifera are the longest studied microfossils of all facies. The assemblages of successive subdivisions differ in age and represent different environmental conditions. Regardles of the long time research of foraminifera of the Podhale Paleogene they were never adequately presented to geological community. Several hydrogeological wells performed in the last few years within the Podhale Basin and the studies of new surface outcrops provided new foraminiferal data and a sort of stimulus to present an up-dated micropaleontological characteristic of subdivisions.

Geological setting

The Paleogene Podhale basin belongs to the much larger structure, so called Central Carpathian Paleogene Basin (Marschalko, 1968). Following interpretation of Tari et al. (1993) the Paleogene Podhale Basin is considered to be a forearc basin associated with B-subduction type of the European plate.

The sedimentary infill of the Paleogene Podhale Basin consists (Figs 1, 2) of: basal conglomerates of a variable thickness, so called Nummulite Eocene (Roniewicz, 1968) — nummulitic limestones, dolomites, conglomerates, hemipelagic marly claystones rich in pelagic microfauna (Globigerina Marls), and the younger units comprising up to ~3,000 m of sandstones, mudstones with siltstones classically termed the Podhale Flysch (Radomski, 1958).

Our study focuses on the Nummulite Eocene cropping out on the foot of the Tatra Mts and reached by numerous wells distributed between Tatra Mts and Pieniny Klippen Belt (Fig. 2).

Facies distribution of Eocene (Fig. 3) suggest the uneven topography of the Mesozoic basement (Fatricum and Hronicum units), most probably related to the long period of karstification, and to extensional faulting at the beginning of the basin formation.

Nummulite Eocene in the Peri-Tatra zone consist of some, up to 100 m thick succession, of shallow-water organodetritic limestones and detrital dolomites (locally with intercalation of carbonate conglomerates) underlain by basal conglomerates of variable thickness. In the Eocene paleogeography this zone formed narrow E–W stretching carbonate platform (Roniewicz, 1969).

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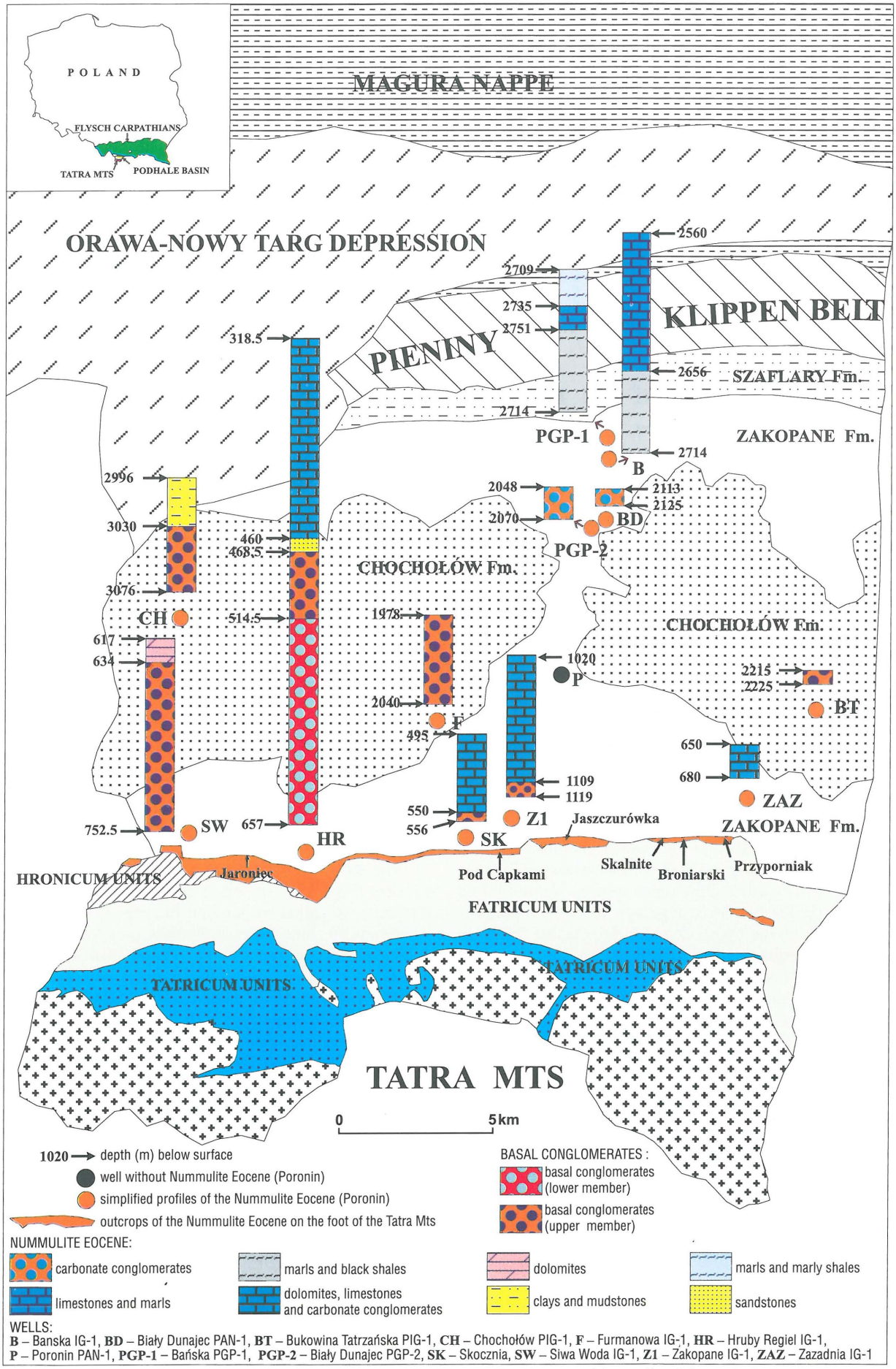

Fig. 1. Localization of outcrops and simplified profiles of the Nummulite Eocene of the wells of the Podhale Basin (based on Polish Geological Institute's documentations and authors' investigations)

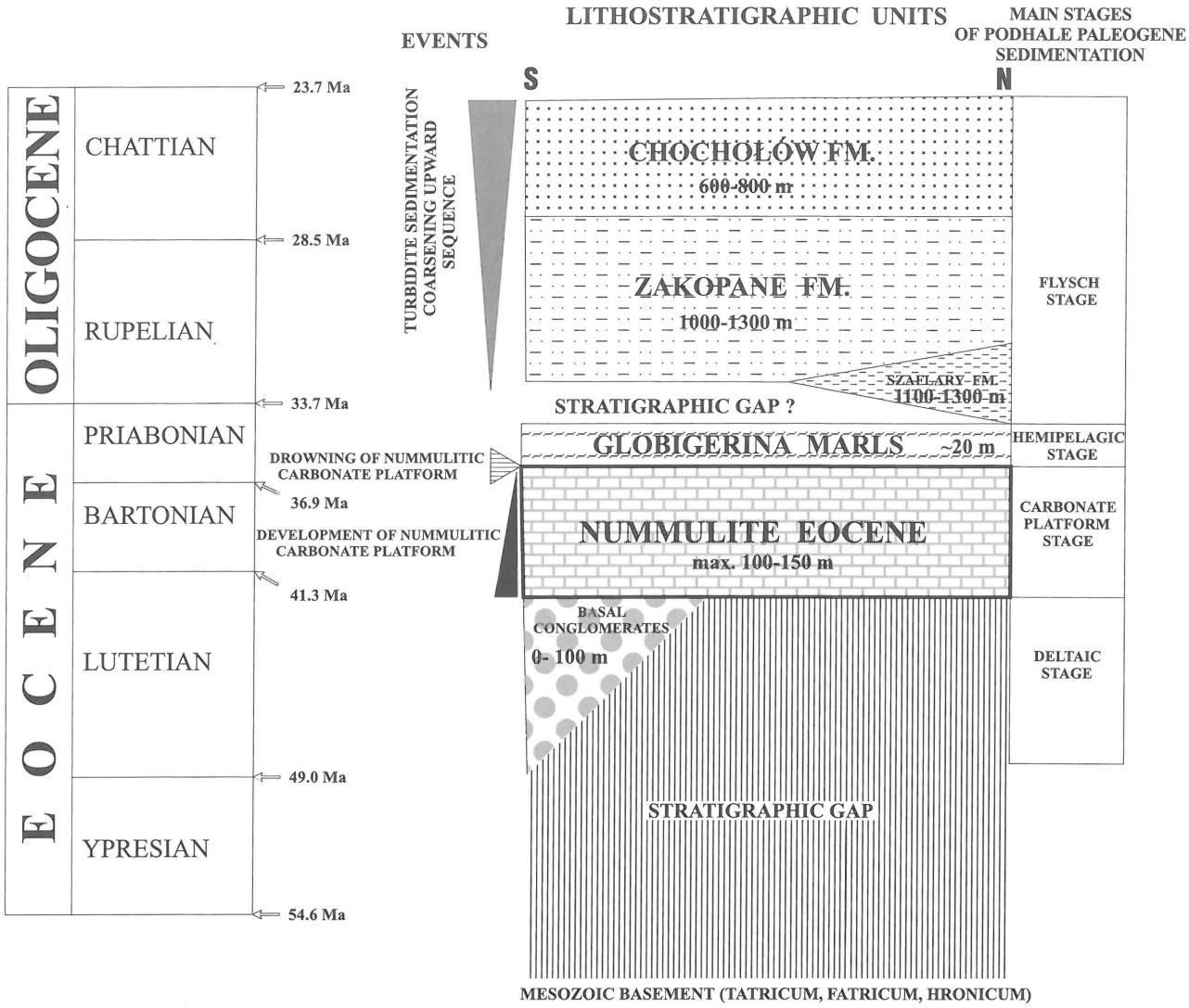

Fig. 2. The Paleogene of the Podhale Basin

In the central part of the Podhale Basin the Nummulite Eocene is developed as carbonate conglomerates with marly matrix. Locally (the Poronin high) this complex is absent.

In the peri-Klippen zone the carbonate complex (limestones, dolomites, marls) is underlain by black shales interfingering with marls, which were, probably, deposited in a downfaulted through of the structurally confined basin.

The Globigerina Marls overlying the Nummulite Eocene document the basin starvation during the period of maximum basin drowning.

The younger flysch succession consists of Szaflary Fm., Zakopane Fm. and Chochołów Fm. attaining the thickness of almost 3,000 m in the peri-Klippen zone. The Szaflary Fm. which distribution is confined to the peri-Klippen zone (maximum extension of the upper part of Szaflary Fm. — up to Poronin area) is considered as deposited along tectonically controlled submarine ramp (Wieczorek, 1989). Deposition of the Zakopane and Chochołów formations, which represent, generally, upward coarsening sequence is probably related to the submarine fans sedimentation

Micropaleontological characteristic

1. The basal conglomerates. The facies is practically devoid of fossils except of some *Lithophagus* borings observed on pebbles in the eastern part of the study area (Roniewicz, 1969).

2. The Nummulite Eocene. The most common feature of all lithotypes is the ubiquitous occurrence of large foraminifera, belonging mainly to genera *Nummulites* and *Discocyclina*. The studies of the large foraminifera had began in late twenties (Bieda, 1929) and are continued to the present day (Bartholdy & Bellas, 1997). The most significant work was done by Bieda (1959, 1960, 1963), who described over 51 species of large foraminifera, designated the age of nummulitic limestones and elaborated stratigraphical scheme based on *Nummulites* species. Later Kulka (1984b, 1985) corrected the scheme indicating environmental rather than evolutionary control of occurrence of successive species. The latter author successfully applied to the Tatra Nummulite Eocene Arni's (1965) model of the carbonate platform sedimentation. Species of genus *Discocyclina* were studied by Olempska (1973).

The considerable significance of the large species for stratigraphy of platform carbonates left small species of the Tatra nummulitic limestones almost unattended. Authors' investigations revealed, in addition to over 50 species of large foraminifera designated by Bieda (1963), Olempska, (1973), and Kulka (1980, 1984a) the occurrence of more than 40 species of small foraminifera predominantly con-

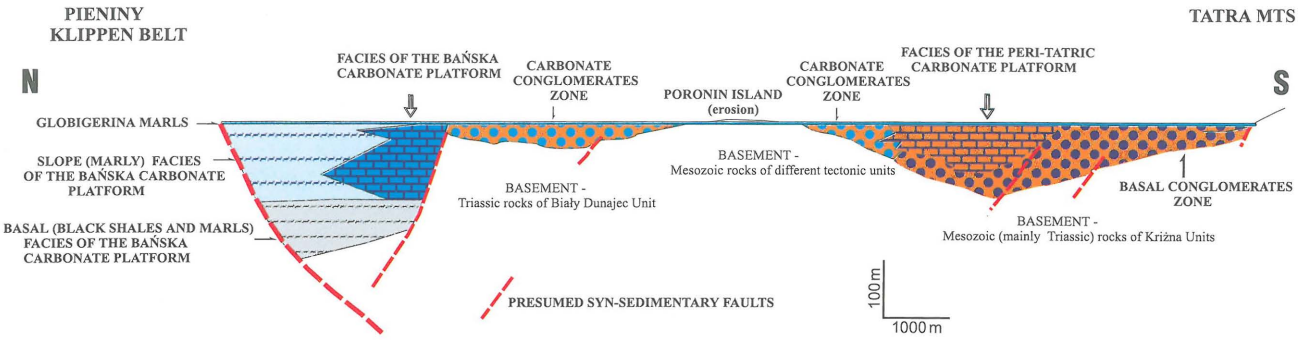

Fig. 3. Facies of the Nummulite Eocene of the Podhale Basin, N–S cross section

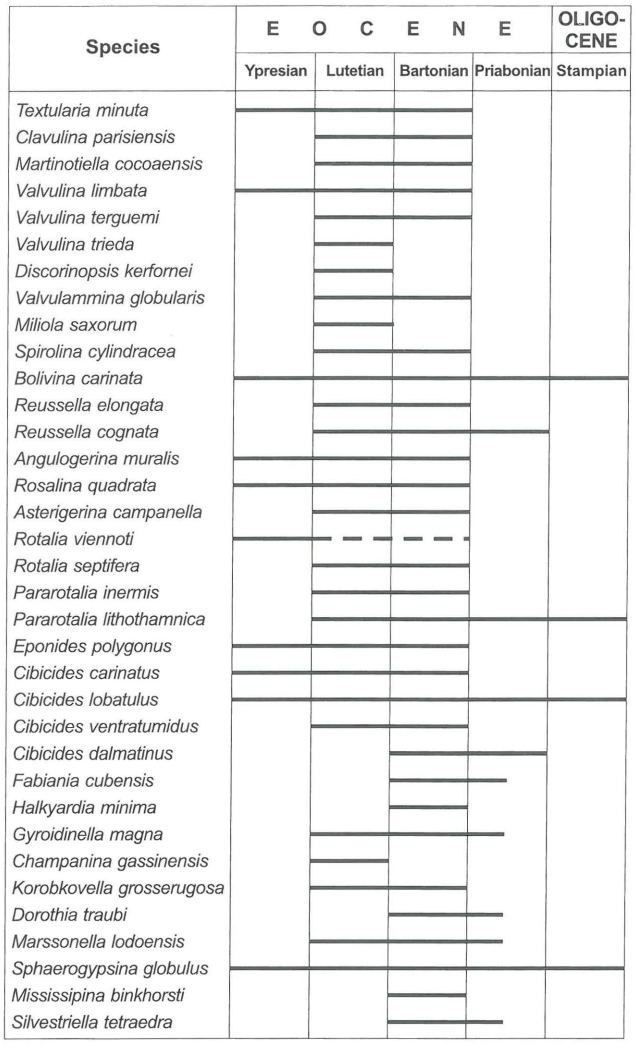

Fig. 4. Stratigraphic distribution of the smaller foraminifera of the Nummulite Eocene

nected with shallow carbonate environment (Olszewska, 1990). Their stratigraphical distribution (Fig. 4) supports Bartonian–early Priabonian age for the major part of the the Nummulite Eocene.

During the late eighties several hydrogeological wells were performed within the Podhale Basin: Chochołów PIG-1, Furmanowa 1, Biały Dunajec PAN-1, Bukowina Tatrzańska PIG-1. They reached deposits of the Nummulite Eocene at various depths completing micropaleontological informations provided by earlier wells i.e.: Siwa Woda IG-1, Hruby Regiel IG-1, Zakopane IG-1, Skocznia IG-1, Bańska IG-1 and surface investigations (Bieda, 1963; Olempska, 1973; Chowaniec & Golonka, 1981).

Chochołów PIG-1 borehole. The Nummulite Eocene occurred at depths: 2,996.0–3,076.0 m. Deposits are extremely poor in microfossils. Study of the thin sections revealed few *Nummulites* cf. *distans* Deshayes, *Discocyclina varians* (Kaufmann) and *Cibicides ventratumidus* Myatlyuk.

Furmanowa 1 borehole. The Nummulite Eocene faunas were found at depths 1,978.0–2,040.0 m. Sublittoral breccia contained clasts of various age and origin: the *Calpionella* limestones, dolomites, spongiolithes, encrinites, *Saccoccoma* limestones. Microsparitic matrix contained fragments of large foraminifera and small species: *Pararotalia lithothamnica* (Uhlig), *Chapmanina gassinensis* (Silvestri), *Martinotiella cocoaensis* Cushman, *Cibicides ventratumidus* Myatlyuk.

Biały Dunajec PAN-1 borehole. The Nummulite Eocene deposits were reached at depths 2,113.0–2,125.0 m. Their micropaleontological content was very poor and contained few sections of *Nummulites* sp.

Bukowina Tatrzańska PIG-1 borehole. The Nummulite Eocene conglomerates were encountered at depths of 2,215.0–2,225.0 m. Fragments of foraminifera occur as bioclasts in microsparitic matrix: *Discocyclina ephipphium* (Schlotheim), *Eorupertia* sp., *Globigerina* cf. *danvillensis* Howe & Wallace as well as fragments of *Lithophyllum densum* Lemoine.

Zakopane IG-1 borehole. The facies of Nummulitie Eocene was reached at depths 1,020.3–1,119.0 m (Sokołowski, 1973). Its foraminiferal content (especially large species) was studied by Bieda (Bieda, *vide* Sokołowski, 1973). *Nummulites* species from depths 1,020.4–1,089.8 m form typical inner to outer shelf succession recognised by Kulka (1985).

Skocznia IG-1 borehole. The Nummulite Eocene occurs at depths 495.5–556.0 m. Foraminiferal assemblages are composed mainly of representatives of *Nummulites* and *Discocyclina* with minor addition of other species: *Pararotalia lithothamnica* (Uhlig), *Textularia minuta* Terquem, *Lobatula lobatula* (Walker & Jacob).

Hruby Regiel IG-1 borehole. Petrographical investigations of the Nummulite Eocene limestones revealed microbiofacies with *Discocyclina* and *Nummulites* at depth 374.1 m (Kuźniar, 1977).

Bańska IG-1 borehole. The Nummulite Eocene was reached at depths 2,560.0–2,714.0 m. The large foraminifera were studied by Kulka (1983). He pointed, as important, species: *Nummulites perforatus* Montfort, *N. millecaput* Boubeé, *N. incrassatus* de la Harpe, *N. striatus* (Bruguiere), *Assilina exponens* (Sowerby) and *Alveolina elongata* (d'Or-

bigny). Assemblages of small foraminifera tend to include more planktic and open sea benthic species towards the top of the profile. The assemblage at depth 2,626.0–2,627.4 m contained: *Cibicides ventratumidus* Myatlyuk, *Lobatula lobatula* (Terquem), *Reussella terquemi* Cushman, *R. elongata* (Terquem), *Asterigerina campanella* (Gümbel), *Gyroidinella magna* (Le Calvez), *Eorupertia cristata laevis* (Grimsdale), *Globigerina danvillensis* Howe & Wallace, *Tenuitellinata* cf., *medizzai* Toumarkine & Bolli, *T.* aff. *angustiumbilicata* (Bolli), *Globanomalina* sp., *Chilogümbelina* sp. In the lower part of the profile (interval 2,650.0–2,651.0 m) species connected with the carbonate platform prevail: *Valvulina triedra* (Terquem), *Gyroidinella magna* (Le Calvez), *Haddonia heissigi* Hagn, *Marssonella* cf. *lodoensis* Israelsky, *Fabiania cubensis* (Cushman & Bermudez), *Pararotalia lithothamnica* (Uhlig), *Miniacina multiloculata* Scheibner. Among rare planktic species *Muricoglobigerina senni* (Beckmann) was identified.

Comparison between foraminiferal assemblages from the surface outcrops of the Nummulite Eocene and those from wells demonstrate their similarity. Among large foraminifera the most common to both were: *Nummulites perforatus* (Montfort), *Nummulites striatus* (Bruguiere), *Discocyclina varians* (Kaufmann), *Asterocyclina stella* Gümbel, *Assilina exponens* (Sowerby) and *Alveolina elongata* (d'Orbigny). Frequency of *Nummulites perforatus* (Montfort) in investigated strata led to designation of Bartonian *Nummulites perforatus* zone in nummulite zonation proposed for the Polish Carpathians by Kulka (1984b). Still more similarity display assemblages of small foraminifera. Almost all species listed on Fig. 4 are common to both investigated sites. It may suggest greater cover of nummulitic facies compared to its present area what resulted in broad distribution of products of its disintegration in time.

3. The hemipelagic marls with planktic foraminifera (the Globigerina Marls). The yellowish-grey marls and marly shales of this subdivision occurs as intercalations in the upper part of the Nummulite Eocene (Alexandrowicz & Geroch, 1963) or as their cover (Blaicher, 1973). The characteristic feature of marls is the dominance of planktic foraminifera (making more than 50% of assemblages) and scarce occurrence of benthic species representing uppermost bathyal environment. Marls with planktic foraminifera were studied both in wells: Hruby Regiel 2, Zakopane IG-1, Bańska IG-1 and in the surface outcrops, localities: Skalnite Brook, Broniarski Gully, Jaroniec Brook, Przyporniak Brook, Olczyska valley, Pod Capkami quarry, „Bluff above the Chapel" in Jaszczurówka (Fig. 1).

Hruby Regiel 2 borehole. The grey marls occurred at depths 158.8 –158.9 m, and contain poor but characteristic assemblage composed of: *Subbotina linaperta* (Finlay), *Globigerina eocaena* Gümbel, *Cibicides ventratumidus* Myatlyuk.

Zakopane IG-1 borehole. The foraminifera of the grey marls were described by Blaicher (1973) from depths 1,005.0–1,020.3 m. The assemblage is rich in both planktic and benthic foraminifera. The presence of numerous *Globigerapsis index* (Finlay) indicates the Late Eocene age. Benthic assemblage is very similar to that reported by Hagn (1956) from Eastern Italian Alps. To the common species belong: *Vulvulina flabelliformis* (Gümbel), *Dorothia traubi* Hagn, *Karreriella exilis* Hagn, *Spiroplectinella guembeli* (Hagn), *Tritaxia kruhelensis* (Wójcik), *Anomalinoides granosus* (Hantken) *Uvigerina eocaena* Gümbel, *Falsoplanulina ammophila* (Gümbel), *Heterolepa perlucida* (Nuttall).

Bańska IG-1 borehole. Assemblages of grey marls occur at depths 1,941.4–2,276.5 m (Gonera, *vide* Sokołowski, 1981). They are composed predominantly of planktic species such as: *Acarinina bullbrooki* (Cushman), *Porticulosphaera mexicana* (Cushman), *Globoquadrina tripartita* (Koch), *Turborotalia increbescens* (Bandy), *Globigerina leroyi* Blow & Banner, *G. officinalis* Subbotina, *Subbotina krosnensis* (Blaicher), *Tenuitella liverovskae* (Bykova). Interesting is the occurrence of two late Middle–early Late Eocene arenaceous species: *Sphaerammina subgaleata* (Vasiček) and *Ammodiscus latus* (Grzybowski) in assemblages just below the grey marls.

Skalnite Brook. A rich planktic assemblage contained, among others (after Gonera, unpublished data): *Cribrohantkenina bermudezi* Thalmann [= *C. inflata* (Howe)], *Globigerapsis index* (Finlay), *Globigerina ampliapertura* Bolli, *Globoquadrina tripartita* (Koch), *Catapsydrax dissimilis* (Cushman & Bermudez).

Broniarski Brook. Samples of the grey marls from the top of the gully contained among others: *Globigerapsis index* (Finlay), *Porticulosphaera mexicana* (Cushman), *Turborotalia cerroazulensis* (Cole), *Globigerina eocaena* Gümbel, *Globoquadrina tripartita* (Koch), *Heterolepa perlucida* (Nuttall).

Jaroniec Brook. Samples from this locality yielded rich and diversified assemblages. Except of the redeposited large foraminifera the most common were: *Globocassidulina globosa* (Hantken), *Reussella cognata* (Terquem), *Heterolepa perlucida* (Nuttall), *Pararotalia lithothamnica* (Uhlig), *Gyroidinella magna* Le Calvez, *Eponides polygonus* Le Calvez, *Globigerina danvillensis* Howe & Wallace, *G. leroyi* Blow & Banner, *Globoquadrina tripartita* (Koch), *Catapsydrax echinatus* Bolli.

Przyporniak Brook. Assemblages of foraminifera from the grey marls are very rich and similar to those known from the well Zakopane IG-1 and Pod Capkami quarry (Alexandrowicz & Geroch, 1963; Blaicher, 1973). Over 45 benthic and 20 planktic species had been recognised. To most common belong: *Karreriella exilis* Hagn, *Tritaxilina hantkeni* Cushman, *Vulvulina eocaena* (Gümbel), *Bulimina truncana* Gümbel, *Heterolepa eocaena* (Gümbel), *Nuttallides trümpyi* (Nuttall), *Osangularia pteromphalia* (Gümbel), *Pleurostomella acuta* (Hantken), *Anomalinoides capitatus* (Gümbel), *Uvigerina multistriata* (Hantken), *Testacarinata rugosoaculeata* (Subbotina), *Globanomalina micra* (Cole), *Globigerapsis index* (Finlay), *Porticulosphaera mexicana* (Cushman), *Globigerina eocaena* Gümbel, *Tenuitella pemicra* Blow & Banner, *Tenuitellinata medizzai* (Toumarkine & Bolli), *Truncorotaloides rohri* Bolli, *Turborotalia pomeroli* Toumarkine & Bolli.

Pod Capkami quarry. Results of the foraminiferal investigations had been already published (Alexandrowicz & Geroch, 1963). The investigated grey marls occur within the Late Eocene Nummulites fabianii (IV) zone (Bieda, 1963). Stratigraphically significant planktic species are: *Globigerapsis index* (Finlay), *Porticulosphaera mexicana* (Cushman), *Turborotalia cerroazulensis* (Cole).

„Bluff above the Chapel" in Jaszczurówka. The outcrop yielded assemblage rich in planktic species such as: *Turborotalia cerroazulensis* (Cole), *Globigerina eocaena* Gümbel, *G. danvillensis* Howe & Wallace, *G. leroyi* Blow & Banner, *G. corpulenta* Subbotina, *Globoquadrina tripartita* (Koch), *Muricoglobigerina senni* (Beckmann), *Globoquadrina tripartita* (Koch).

The survey of the grey marls foraminiferal assemblages indicate great uniformity of faunas, with planktic species

suggesting P15–P16 foraminiferal zones and benthic species indicating neritic-upper bathyal depths.

4. The Podhale flysch. The Szaflary Fm. The coarse clastic deposits of the formation in many localities are devoid of foraminifera or contain redeposited forms. Thin sections of this subdivision in the Bańska IG-1 well, examined by Kulka *(vide* Sokołowski, 1981) revealed assemblage of large foraminifera with frequent *Alveolina elongata* d'Orbigny and *Assilina exponens* (Sowerby) rare in surface outcrops of the Nummulite Eocene. Washed samples (Gonera, *vide* Sokołowski, 1981) contained rare planktic species: *Globigerina officinalis* Subbotina, *G.* ex gr. *praebulloides* Blow, *Tenuitella liverovskae* (Bykova) indicating at least Latest Eocene age.

Szaflary. The sample was collected by Kulka from the site described by Kuźniar (1910) about 2 m from the contact with the Pieniny Klippen Belt. The foraminifera designated in thin sections are mainly large species: *Nummulites perforatus* (Montfort), *Nummulites fabianii* Prever, *Grzybowskia multifida* Bieda, *Orbitoclypeus nummuliticus* (Gümbel). They indicate Late Eocene age for the assemblage.

Niedzica. Washed samples from the Jędruś Brook contained poor assemblages composed of arenaceous species and few planktics: *Chilogümbelina gracillima* (Andreae), *Parasubbotina karpatica* (Myatlyuk), *Tenuitella* cf. *liverovskae* (Bykova). The planktic species indicate at least Latest Eocene age. Numerous arenaceous species are probably redeposited, judged from their known stratigraphic distribution in the Outer Carpathians.

The Zakopane Fm. Foraminiferal characteristic of this subdivision is based on samples from wells: Zakopane IG-1, Bańska IG-1, Bukowina Tatrzańska IG-1 and numerous surface outcrops. Dark shally deposits of the subdivision yielded over 40 species of foraminifera. To the most frequent benthic species belong: *Allomorphina trigona* (Reuss), *Chilostomella tenuis* (Bornemann), *Virgulinella chalkophila* Hagn, *Fursenkoina schreibersiana* (Čžjžek), *Cibicides lopjanicus* Myatlyuk, *C. amphisylensis* (Andreae), *Brizalina subdilatata* (Subbotina). The assemblage as indicated by Blaicher (1973) is identical to that characteristic for the Lower Krosno Beds (Late Rupelian) of the Outer Carpathians. Planktic foraminifera of the Zakopane Fm. are represented by: *Globigerina praebulloides-officinalis* group, and rare: *G. ampliapertura* Bolli, *Chilogümbelina gracillima* (Andreae), *Tenuitellinata ciperoensis* (Bolli), *Paragloborotalia nana* (Bolli), *Tenuitella liverovskae* (Bykova), *Parasubbotina karpatica* (Myatlyuk). Species of large foraminifera from sandstones and conglomerates of the Zakopane Fm. (Koszarski & Sikora, 1971) represent the Late Eocene *Nummulites fabianii* zone of Bieda (1963).

Chochołów Fm. The psammitic deposits of the Chochołów Fm. are very poor in foraminifera. Sandstones and conglomerates contain fragments of Nummulite Eocene with large species, Zakopane Fm. shales with small *Globigerina* and other sedimentary and magmatic rocks. Washed samples (e.g. Kacwiński Brook) contained few specimens of *Globigerina praebulloides* Blow and *G. officinalis* Subbotina suggesting the age not older than the Late Eocene.

Data from other microfossils

The calcareous nannoplankton. This group of microfossils was studied by Dudziak (1983, 1984, 1986, 1993), Bartholdy et al. (1995) and Smagowicz (*vide:* Chowaniec et al., 1992; Poprawa et al., 1992). The nannoplankton species of the grey marls from the Pod Capkami quarry (Bartholdy et al., 1995) indicated Bartonian (upper NP16–lower NP17 zone) age for this subdivision. The calcareous nannoplankton from the Szaflary Fm. at Kacwin (south of Pieniny Klippen Belt) was assigned to the early Priabonian NP18 zone (Dudziak, 1993). The age of the Zakopane Fm. after Dudziak (1983, 1984, 1986) is restricted to the Late Eocene (NP17–NP19/20), while Chochołów Fm. and its upper part the Ostrysz Beds represent the Early Oligocene (NP21–NP22). Different age for the Podhale flysch was designated by Smagowicz (*vide* Chowaniec et al., 1992; Poprawa et al., 1992). After Smagowicz, grey marls in the Bańska IG-1 contain *Istmolithus recurvus* Deflandre indicating the Late Priabonian NP19/20 zone. Deposits of the Szaflary Fm. in wells Bańska IG-1, Chochołów IG-1, as well as from outcrops at Kacwin and Niedzica containing: *Istmolithus recurvus* Deflandre, *Lanternithus minutus* Stradner, *Ericsonia subdisticha* (Roth & Hay) and *Sphenolithus pseudoradians* Bramlette & Wilcoxon represent the same zone. The nannoplankton assemblages of the Zakopane Fm. in wells Bukowina Tatrzańska IG-1, Furmanowa IG-1, and Chochołów IG-1 composed of: *Sphenolithus distentus* Bramlette & Wilcoxon, *S. dissimilis* Bukry & Percival, *Reticulofenestra abisecta* Müller indicate late Rupelian–Early Chattian (NP23–NP24) for the main volume of this subdivision. The Chattian or even younger age (at least NP24) was suggested for the Chochołów Fm. by the latter author who reported the presence of *Helicosphaera ampliaperta* Bramlette & Wilcoxon in the topmost part of subdivision (depth 999.5 m) in well Furmanowa IG-1.

The dinoflagellates. The dinoflagellates of the Podhale flysch were studied by Gedl (1995, 1998). The age of the? younger part of the Szaflary Fm. was designated as Oligocene based on the presence of *Wetzeliella gochtii* and *Chiropteridium lobospinosum* in wells Chochołów IG-1 and Biały Dunajec PAN-1. The middle Rupelian age was assigned for the Zakopane Fm. based on cooccurrence of *Wetzelliella symmetrica* and above mentioned dinoflagellate species. Tentative Late Chattian age for the upper part of the Chochołów Fm. was assigned on the presence of *Distatodinium biffi* although according to Gedl (1998) the redeposition of specimens (? from the lower part of the Chochołów Fm.) should be taken into account. The author (Gedl, 1995) mentions the relative abundance of the genus *Chiropteridium* in the top of the studied sections. Similar phenomenon was observed in the Central Italy close to the Oligocene–Miocene boundary (Biffi & Manum, 1988)

Remarks on stratigraphy

The stratigraphical results of investigation can be summarised as follows:

The large and small foraminifera found in the Nummulite Eocene suggest Bartonian–Early Priabonian age for this subdivision. The Priabonian age is based on occurrence in the upper part of the sequence species: *Tenuitellinata medizzai* (Toumarkine & Bolli), *Globigerina danvillensis* Howe & Wallace, *Nummulites fabianii* Prever, *Grzybowskia multifida* Bieda, *Operculinoides nassauensis* (Cole), *Spiroclypeus granulosus* Boussac. The grey marls with Globigerina represent the P15–P16 foraminiferal zones (Berggren & Miller, 1988). This assumption is based on the presence of numerous *Globigerapsis index* (Finlay), *Porticulosphaera mexicana* (Cushman), *Turborotalia cerroazulensis* (Cole), *T. increbescens* (Bandy) in the lower part of the subdivision

and *Globoquadrina tripartita* (Koch), *Cribrohantkenina inflata* (Howe) and *Globorotalia cocoaensis* Cushman in the upper part. The calcareous nannoplankton represents NP16–NP17 zones in the Pod Capkami quarry (Bartholdy et al., 1995) and the NP19/20 zone in subsurface samples (Smagowicz, *vide:* Chowaniec et al., 1992; Poprawa et al., 1992).

The foraminifera in the lower part of the Podhale flysch (i.e. Zakopane Fm.) make very distinctive assemblage analogous to the upper Rupelian assemblages of the Outer Carpathians with characteristic species *Virgulinella chalkophila* (Hagn). Faunas from remaining subdivisions are not significant and contain reworked species. The results of investigations of the calcareous nannoplankton from deposits of the Podhale flysch remain controversial. After Dudziak (1993) the Szaflary Fm. represents the early Late Eocene (NP18 zone), the Zakopane Fm.–the Late Eocene (NP17–NP19/20 zones) and the Chochołów Fm.–the Early Rupelian (NP21–NP22 zones). The younger age was assigned to discussed subdivisions by Smagowicz (*vide:* Chowaniec et al., 1992; Poprawa et al., 1992). The latter author referred Szaflary Fm. to the NP19/20 nannofossil zone, the Zakopane Fm. mostly to the NP23–NP24 zones and the Chochołów Fm. to the NP24–NN1 zones. Studies on dinoflagellates (Gedl, 1995, 1997) confirmed Oligocene age for the whole succession.

Remarks on environment

The distinctive lithological features of the Paleogene deposits of the Podhale Basin facilitated environmental interpretations carried out simultaneously with geological studies (Passendorfer, 1951, 1958, 1959; Wyczółkowski, 1956). From the very beginning fossils were used for these interpretations (Szafer, 1958; Bieda, 1959; Passendorfer 1959) supporting geological observations. Recent progress in environmental research of different groups of fossils make possible some improvement in these interpretations.

The basal conglomerates. They were regarded as deposits of fluvial to marine cliff origin (Passendorfer, 1959).

The Nummulite Eocene. The origin of the Nummulite Eocene is connected with the Mid-Eocene transgression and expansion, in relatively mild climate, shallow carbonate environment on shelves (Haq et al., 1977; Hay et al., 1981). Recent investigations demonstrated that the Nummulite Eocene deposits accumulated in different microenvironments of the shallow water carbonate platform. Several of Arni's model biofacies (Arni, 1965) had been identified in successive profiles (Kulka, 1985; Bartholdy et al., 1995). Kulka (1985) identified the following succession of biofacies (from the shallowest): D — dolomitic limestone with *Nummulites brongniarti*, C — the back bank dolomitic limestones with *Nummulites puschi*, B — the *Nummulites* bank with *Nummulites perforatus*, A — the fore bank *Discocyclina* limestone with *Nummulites millecaput*. According to Bartholdy et al. (1995) biofacies A–C represent the shallow subtidal environment with depths oscillating between 20 to 80 m. An energy index values calculated by Kulka (1985) for the successive facies indicated that D and C biofacies accumulated in agitated waters while B and A biofacies represent quieter environments. Distribution of small foraminifera follows similar pattern. In D biofacies only single specimens of *Gypsina* had been found. In C biofacies increases the number of hard substrate dwellers, among others *Pararotalia* ssp. In the moderately agitated water of the *Nummulite* bank biofacies increases diversification of small foraminifers. Besides characteristic hard substrate/high energy genera as: *Fabiania*, *Calcarina*, *Lockhartia*, *Pararotalia*, *Gyroidinella*, *Halkyardia* and *Chapmannina* (Hottinger, 1983) occur those preferring softer substrate and less agitated waters: *Reussella*, *Eponides*. The A biofacies composed of *Discocyclina* and *Nummulites millecaput* with large and flat tests is connected with strongest marine influence since tests of large foraminifera became more compressed in deeper habitats (Hottinger, 1983). The small foraminifers are abundant with increase of soft substrate, low energy, outer shelf genera: *Textularia*, *Valvulammina*, *Vulvulina*, *Marssonella*, *Dorothia*, *Martinotiella*, *Angulogerina*, *Cibicides*, *Heterolepa*, *Asterigerina*. Hard substrate dwellers such as *Pararotalia*, *Gyroidinella*, *Fabiania*, *Heterostegina* or *Spiroclypeus* are also present. Planktic foraminifera are frequent.

The presence of: *Nummulites brogniarti*, *Nummulites fabianii*, *Grzybowskia* (*Heterostegina*), and *Chapmanina* confirms location of the study area within the NW part of Tethys Ocean (Fleury et al., 1985).

The grey marls with planktic foraminifera

This subdivision is thought to be of hemipelagic origin on a base of abundant planktic foraminifera. In majority of samples they make over 50% of total assemblage. Abundant occurrence of genera *Globigerapsis* and *Porticulosphaera* makes the assemblage a Carpathian example of the Middle–Late Eocene, middle to high latitude Globigerinatheka assemblage of pelagic realm (Haq et al., 1977).The shift of the Globigerinatheka assemblage into higher latitudes may be correlated with the Middle/Late Eocene climatic cooling event (Hallock et al., 1991; Oberhänsli, 1996). The specific composition of benthic assemblages strongly resemble faunas known from the Hungarian *Tritaxia szaboi* Beds (Sztrakos, 1987) and Monte Brione of Italian Alps (Hagn, 1956). From over 60 species of benthic foraminifera designated from the grey marls about 30 are in common with mentioned faunas. Especially similar to benthic assemblage of grey marls are faunas of the late Bartonian–Early Priabonian Halimba Formation of Hungary that accumulated at the shelf edge (about 200 m) (Sztrakos, 1987). To the common species belong: *Clavulinoides kruhelensis* Wójcik, *Cylindroclavulina colomi* Hagn, *Spiroplectinella adamsi* (Lalicker), *Martinotiella cocoaensis* Cushman, *Tritaxilina hantkeni* Cushman, *Bolivina crenulata* Cushman, *Bulimina truncana* (Gümbel), *Falsoplanulina ammophila* (Gümbel), *Heterolepa eocaena* (Gümbel), *Pleurostomella acuta* Hantken, *Uvigerina rippensis* Cole, *U. multistriata* (Hantken), *Reussella elongata* (Terquem). Persistent presence of some bathyal elements such as *Pleurostomella* ssp. *Nuttallides truempyi* (Nuttal), *Osangularia pteromphalia* (Gümbel) as well as some arenaceous species: *Haplophragmoides suborbicularis* Grzybowski, *H. walteri* (Grzybowski), *Trochamminoides coronatus* Brady, suggest for the grey marls uppermost bathyal depth of deposition (Berggren & Miller, 1989). This type of faunas are also known in the Outer Carpathians from the subaqueous slump deposits (Blaicher, 1961).

The Podhale flysch. Periodical stagnation of bottom water is indicated by pyritised specimens of the „low oxygen" faunas (*Virgulinella chalkophila*, *Chilostomella tenuis*, *Fursenkoina schreibersiana*) of the lower part of the Zakopane Fm. Calcareous nannoplankton of the formation is sometimes enriched in the shallow water species *Lanthernitus minutus*. The dinocysts assemblages of the Ostrysz Beds

are dominated by the shallow water taxa: *Homotryblium* and *Glaphyrocysta* (Gedl, 1995). Genus *Homotryblium* indicates subtropical climatic conditions during sedimentation of the Podhale flysch (Brinkhuis, 1994). Frequency of terrestrial elements (palynomorphs), near shore dinocysts and shallow water calcareous nannoplankton suggests considerable terrestrial influx into turbidite basin of the Podhale flysch.

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