The Tithonian–earliest Berriasian *Nannoconus* zones in selected sections of the Pieniny Klippen Belt and the Western Tatra Mountains (southern Poland)  

(Figs 1–20; Tabs 1, 2)

Abstract. In comparison with the Spanish sections, first appearance (FAD) of the Tithonian *Nannoconus* species is recorded earlier in the Pieniny Klippen Belt and the Western Tatra Mountains (Western Carpathians). The Early Tithonian *Nannoconus compressus* Zone correlates with the uppermost part of the “Pulla-Tithonica” Zone and the lower part of the Malmica Zone. The *N. infans* Zone corresponds to the upper part of the Malmica Zone and the lower part of the *Chitinoidella* Zone (Dobeni Subzone) including the lowermost interval of the Boneti Subzone. The *N. wintereri* Zone is equivalent to the uppermost part of the *Chitinoidella* Zone, entire *Crassicollaria* Zone, and the basal interval of the Berriasian Alpina Subzone. In the Kryta Valley section (Tatra Mts), the Infans/Wintereri zonal boundary is located within the Boneti Subzone and is correlated with the lower part of the CM20n magnetozone. Specimens referred to *Nannoconus* sp. A occur in the studied sections; these specimens differ from the published descriptions of all previously established Tithonian species. In the Lower Tithonian limestones nannoconids are scarce being more numerous in the lower interval of the *N. wintereri* Zone. Increase in abundance of the genus *Nannoconus* correlates with the Mid- to Late Tithonian Nannofossil Calcification Event (NCE) reported from the Central Atlantic Ocean.

Key words: *Nannoconus*, stratigraphy, Tithonian, Berriasian, Pieniny Klippen Belt, Western Tatra Mountains, Carpathians, Poland.

INTRODUCTION

This study of the Tithonian *Nannoconus* assemblages was conducted in the Pieniny Klippen Belt (PKB) and the Tatra Mountains, southern Poland (Fig. 1). These assemblages have been studied in the following sections (Fig. 1C and 1D):
Stare Bystre, Wapiennik, Kapuśnica I, Gacówka (PKB, the Branisko Succession), Grajcarek (the Magura Succession) and the Kryta Valley (Western Tatra Mountains). The nannoconids have been studied under the JEOL scanning electron microscope (JSM 840A) in fresh chips taken from the limestone samples. The microfossils have been identified and photographed from thin sections under the OLYMPUS and NIKON Eclipse LV100 POL light microscopes. In this *Nannoconus*—
oriented study only final results of the microfossil analysis necessary for stratigraphical location of the studied samples are reported. The main objective of this paper was to present all data important for the _Nannocyonus_ zonation of the Tithonian strata studied in the above-mentioned sections. The zonation proposed herein is also compared with the previous publications pertinent to this topic.

**PREVIOUS RESEARCH**

Brönnimann (1955) has described and illustrated 10 _Nannocyonus_ species from the Lower Cretaceous limestones of north-central Cuba. This author considered _N. steinmanni_ Kampptner, 1931, to be the oldest _Nannocyonus_ species occurring in the lowermost Cretaceous limestones. In Mexico, Trejo (1960) has established 6 _Nannocyonus_ zones (A–F) between Upper Tithonian and Albian. His Zone A embraced a part of the Upper Tithonian, whereas the Zone B comprised the topmost Tithonian and Lower Berriasian. However, the age of the Zone A was uncertain as no Late Tithonian species of _Crassicollaria_ have been reported to occur together with _Nannocyonus broennimanni_³ (Trejo, 1960). According to Báldi-Beke (1964), the oldest nannoconid species are known from the Lower Tithonian. However, the species _Nannocyonus dolomiticus_ Cita et Pasquaré, 1959 and _N. broennimanni_ Trejo, 1959 have not been identified in the Lower Tithonian strata from Hungary (Báldi-Beke, 1964). Deres and Archéritéguy (1980) correlated their _Nannocyonus steinmannii_ Zone with the Upper Tithonian–Berriasian. Bralower _et al._ (1989) have distinguished the Berriasian _Nannocyonus steinmannii minor_ Subzone (=NJK-D Subzone) and _N. steinmannii steinmannii_ Zone (=NK-1 Zone). Also, these authors created new species and subspecies of the genus _Nannocyonus_ Kampptner, 1931 (_N. compressus_, _N. infans_, _N. wintereri_, _N. kamptneri minor_ and _N. globulus minor_) occurring in the stratigraphic interval from the Middle and Upper Tithonian to Middle Berriasian. In Spain, Tavera _et al._ (1994) subdivided the NJK Zone of Bralower _et al._ (1989) on the basis of first occurrences of _Nannocyonus infans_ Bralower, _N. wintereri_ Bralower et Thierstein and _N. steinmannii minor_ Deres et Archéritéguy (Tab. 1). Tavera _et al._ (1994) placed the first occurrence (FO) of _N. infans_ within the lower part of the calpionellid Intermedia Subzone of the _Crassicollaria_ Standard Zone. The first occurrence of _N. infans_ was considered by these authors to be an earlier event as compared with data presented by Bralower _et al._ (1989). The FO of _N. wintereri_ was placed in the upper part of the Intermedia Subzone and the FO of _N. steinmannii minor_ was slightly older than the _Crassicollaria/Calpionella_ zonal boundary (Tavera _et al._, 1994). Pszczółkowski _et al._ (2005) have identified the _N. wintereri_ Subzone in the latest Tithonian and earliest Berriasian of western Cuba. It became clear that existing Tithonian zonal scheme based on _Nannocyonus_ species needs some changes. Subsequently, a new _Nannocyonus_-based zonal scheme for the Tithonian was proposed (Pszczółkowski, 2006).

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³ This original name used by Trejo (1960) was later changed for _N. broennimanni_ (Deres & Archéritéguy, 1980).
Nannoconus Zones compared to earlier nannofossil zonations correlated with calcipellid scheme and magnetostratigraphic scale

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<td>Polarity</td>
<td>Stage</td>
<td>Substage</td>
<td>Calpionellids after Remane, 1997; calcereous dinocysts after Raphako, 2000b</td>
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<td>145</td>
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<td>C. borzai</td>
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Table 1

- Boundaries correlated with the magnetostratigraphic scale in the Brodno section after Houša et al. (1999).
- Correlation of the J/K boundary with magnetostratigraphy after Bralower et al. (1989).
- J/K boundary in Spain after Tavera et al. (1994); N. wintereri; ‘NCE’ – Nannofossil Calcification Event.
STUDIED SECTIONS: LOCATION, LITHOSTRATIGRAPHIC POSITION OF SAMPLED STRATA AND CALCAREOUS NANNOFOSILS

Stare Bystre section (B in Fig. 1C)

This section was named (“Stare Bystre - school”), described and assigned to the Branisko Succession by Birkenmajer (1958, 1979). The whole section is overturned, so the rock units appear in reversed position (Birkenmajer, 1958, 1979). The red radiolarite of the Buwałd Radiolarite Member (Czajakowa Radiolarite Fm. – Birkenmajer, 1977) is Late Oxfordian in age (Fig. 2) as indicated by presence of “Colomisphaera” fibrata (Nagy, 1966). Up-section, thin red radiolarite is tectonically wedged between the limestones of the Czorsztyn Limestone Formation. In this section, the Early Tithonian age of the red radiolarite reported by Golonka and Sikora (1981) is not confirmed by the present study. The Czorsztyn Limestone Formation is represented mainly by red nodular limestones about 8 m thick (Figs 3 and 4: 1). These limestones are massive in the lower part (Fig. 4: 1-a) and slightly marly in the upper one (Fig. 4: 1-b); their age is Kimmeridgian (Late Kimmeridgian, mainly)–Early Tithonian (Fig. 5).

The Early Tithonian ammonites have been collected from the upper part of the Czorsztyn Limestone Formation (Myczyński, in Pszczółkowski & Myczyński, 2008), between samples By-9 and By-10 (Figs 2 and 3). These ammonites indicate that the Kimmeridgian/Tithonian boundary is located below the sample By-9 (Fig. 2). Chitinoidellids and/or calpionellids have not been found in the Czorsztyn Limestone Fm. in the Stare Bystre section. Therefore, it seems that the upper boundary of this formation does not correspond to the upper boundary of the “red nodular limestones” described by Golonka and Sikora (1981, p. 9 and fig. 3). The boundary between the Czorsztyn Limestone Formation and the Dursztyn Limestone Formation (Birkenmajer & Myczyński, 2000) is located at the base of the Early Tithonian Malmica Zone (Fig. 2). The Dursztyn Limestone Formation is composed of (1) cream to white platy limestone 1.5 to 2 m thick (Fig. 4: 2), sometimes bioturbated (Fig. 4: 3) and (2) reddish nodular limestone, yellow on weathered surfaces, about 5 m thick (Fig. 5). The latter lithologic horizon was named the calpionellid limestone, transitional between the Dursztyn Limestone Formation and the Pieniny Limestone Formation (Birkenmajer, 1979). The Dursztyn Limestone Formation exposed in the Stare Bystre section is Early Tithonian–Early Berriasian in age (Fig. 2). The basal part of the formation has been assigned to the Malmica Zone (sensu Reháková, 2000b), whereas the youngest limestone beds represent the Alpina Subzone (Fig. 2). A stratigraphical condensation (or hiatus?) is probable at the boundary of the Chitinoidella and Crassicollaria Zones. The J/K boundary is indicated at the base of the Alpina Subzone, 5.6 m above the contact of the Czorsztyn Limestone Formation with the Dursztyn Limestone Formation.

The Upper Kimmeridgian–Lower Tithonian nodular limestones of the Czorsztyn Limestone Formation contain few nannofossil taxa only (Fig. 6). The specimens observed and documented in SEM belong mainly to genera Watznaueria.
Fig. 2. Microfossil stratigraphy of the Late Jurassic–earliest Cretaceous strata exposed at Stare Bystre (Pieniny Klippen Belt). 1 – red radiolarite; 2 – thick-beded red nodular limestone; 3 – red marly nodular limestone; 4 – red marl; 5 – red bioclastic limestone; 6 – platy limestone; 7 – thick-beded pale red nodular limestone; 8 – tectonic contacts; 9 – taxon occurrence (confirmed); 10 – probable occurrence of a taxon (cf.)
First occurrence of *Nannoconus* was recorded from the Lower Tithonian limestone, slightly below the base of the Malmica Zone, close to the base of the Dursztyn Limestone Formation. The position of the base of Malmica Zone may be defined indirectly, as the Tithonica/Malmica boundary was correlated with the Darwini/Semiforme bound-

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Fig. 3. Upper part of the Czorsztyn Limestone Formation exposed in the Stare Bystre section. Location of samples By-9 and By-10 is indicated (see also Fig. 2). The nodular limestone occurs in a reversed position and the strata are dipping to the left.
ary interval (Reháková, 2000a). The Early Tithonian Darwi/Semiforme boundary was correlated with the upper part of the M22n magnetozone (Gradstein et al., 2004). Therefore, the Malmica Zone sensu Reháková (2000a, b) is significantly narrower than the zone used by Nowak (1976).
Five *Nannoconus* biozones have been identified in the Stare Bystre section (Fig. 6). The lowermost *N. compressus* Zone is thin and poorly documented, with *N. cf. compressus* Bralover et Thierstein 1989, only. The younger *N. infans* Zone is tentatively recognized on the basis of *N. cf. infans* Bralover, 1989 (Fig. 7: 4) presence. Specimens assigned to *Conusphaera mexicana* Trejo subsp. *mexicana* Bralower, Monechi et Thierstein 1989 (Fig. 7: 1), *Nannoconus* sp. A (Fig. 7: 2) and *N. cf. compressus* Bralover et Thierstein 1989 (Fig. 7: 3) also occur in this *Nannoconus* Zone. The next *N. wintereri* Zone, based on the index taxon occurrence (Fig. 7: 6), embraces the Upper Tithonian–basal Berriasian limestones. The taxa *N. compressus* (Fig. 7: 5) and *N. sp. A*, are also present. The Lower Berriasian limestone (sam-
Fig. 6. Distribution of calcareous nanofossils and nannoconid stratigraphy in the Tithonian–earliest Berriasian strata exposed at Stare Bystre (Pieniny Klippen Belt). 1–10: see Fig. 2 for explanation
Fig. 7. Calcareous nannofossils from the Czorsztyn Limestone Formation (7, 8) and the Dursztyn Limestone Formation (1–6) at Stare Bystre (Pieniny Klippen Belt): 1 – *Conusphaera mexicana* Trejo mexicana Bralower, Monechi et Thierstein, 1989, sample By-13A (Chitinoidella Zone, Early Tithonian); 2 – *Nannoconus* sp. A (slightly oblique longitudinal section), sample By-10B (Malmica Zone, Early Tithonian); 3 – *Nannoconus* sp. cf. *N. compressus* Bralower et Thierstein, 1989 (longitudinal section), sample By-13A (Chitinoidella Zone); 4 – *N. cf. infans* Bralower, 1989 (slightly oblique longitudinal section), sample By-13 (Chitinoidella Zone, Early Tithonian); 5 – *N. compressus* Bralower et Thierstein, 1989 (slightly oblique longitudinal section), sample By-14 (Boneti Subzone, Late Tithonian); 6 – *N. wintereri* Bralower et Thierstein, 1989 (transverse section), sample By-16 (Intermedia Subzone, Late Tithonian); 7 – *Watznaueria barnesae* (Black 1959) Perch-Nielsen, 1968 (distal view), sample By-8C (Late Kimmeridgian); 8 – *W. ovata* Bukry, 1969 (distal view), sample By-8-A1 (Borzai Zone, Late Kimmeridgian)
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<td>HR-11</td>
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**Zone/ Subzones**

|                          | STAGE/SUBST. | W. valida | C. mexicana | N. sp. A | N. compress | N. winteri | Cy. margherita | N. sp. | W. crassa-
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<td>N. winteri Zone</td>
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**Microfacies**

- K: Crassostrea intermedia
- G-R: Calpionella alpina
- S-G: Lingula intermedia

**Outcrop**

- 1: Calcereous nannofossils
- 2: Lithic log and position of samples
- 3: Samples collected from the rubble
- 4: Tectonic contact
- 5: HR - samples taken by R. Więtczak.
ple By-19) contains *Nannoconus kamptneri* Brönnimann subsp. minor Bralower, 1989. This taxon was reported to co-occur with *N. steinmannii minor* (FAD – Bralower et al., 1989; see also Tab. 1). Therefore, presence of *N. kamptneri minor* in the Stare Bystre section (Fig. 6) documents the *N. steinmannii minor* (Sub)Zone. The topmost limestone bed (By-20) yielded taxa *N. steinmannii minor* and *N. steinmannii steinmannii* and *N. wintereri*; therefore, it belongs to the lower interval of the *N. steinmannii steinmannii* Zone (NK-1) of Bralower et al. (1989).

**Wapiennik klippe section (W in Fig. 1C)**

The Wapiennik klippe is located at the outlet of the Harcygrund Valley (Birkenmajer, 1977, fig. 7), but now is no longer exposed except its uppermost part composed of the Valanginian limestones about 1 m thick. The klippe was blown up and subsequently submerged when the dam was constructed and the Czorsztyn artificial lake has formed. The original cross-section of the klippe was shown by Birkenmajer (1958, 1979). Więtczak (1999) studied stratigraphy and microfacies of the exposed Czorsztyn and Pieniny Limestone formations there. The main results of the Więtczak’s (1999) unpublished study of the Wapiennik klippe are shown in the left column in Fig. 8. Prof. Andrzej Wierzbowski (Geology Faculty of the Warsaw University) kindly made accessible for this study the rock samples taken by R. Więtczak (right column in Fig. 8). These samples, labelled HR, correspond to the original ones used by Więtczak (1999), although a part of them have been re-named (as RW/1/1 to 11). During the present study, additional samples have been collected (MRW, PM) from the rubble of the destroyed klippe used for the dam construction. The stratigraphic position of these samples is based on the results of microfossil analysis (Fig. 8), although their precise location in the original section could not be restored.

The present study has shown that the Czorsztyn Limestone Formation exposed in the Wapiennik klippe comprises also the Lower Tithonian limestones in the basal part of the section (Fig. 8). Some of the studied samples from the rubble are rich in small ammonite shells and *Saccocoma* ossicles, but do not contain any index Tithonian microfossils. These samples are not included in the set of data presented in Fig. 8; their age is an open question and may be Early Tithonian or even Kimmeridgian (?). The samples PM-4a and MRW-1 (from the rubble) contain chitinoi-dellids of the Dobeni Subzone (*Chitinoidella* Zone). The former
Fig. 9. *Nannoconus* spp. from the Czorsztyn Limestone Formation (Upszar Limestone Mbr) in the Wapiennik klippe near Harcygrund Valley (1–7) and the Kapuśnica I section (8, 9); for location see Fig. 1C and Birkenmajer (1977, fig. 7H): 1, 2 – *Nannoconus* sp. A (longitudinal sections), sample PM-4a, Dobeni Subzone, Early Tithonian; 3 – *N. wintereri* Bralower et Thierstein, 1989 (oblique section), sample HR-6, Intermedia Subzone, Late Tithonian; 4 – *N. infans* Bralower, 1989 (oblique section), sample MRW-5, *Praetintinnopsella* Zone, Late Tithonian; 5, 6 – *N. wintereri* Bralower et Thierstein, 1989 (oblique sections), sample MRW-5 (5) and HR-6 (6); 7 – *N. cf. compressus* Bralower et Thierstein, 1989 (slightly oblique longitudinal section), sample MRW-5; 8, 9 – *N. compressus* Bralower et Thierstein, 1989 (oblique sections), samples K-03 (8) and K-04 (9), Early Tithonian
sample (PM-4a in Fig. 8) contains also calcareous nannoplankton with *Watznau-ueria ovata* Bukry, 1969, *Conusphaera mexicana* Trejo, 1960 and *Nannoconus* sp. A (Fig. 9: 1, 2). The sample PM-4a probably belongs to the older *Nannoconus* assemblage, but its zonal assignment is unclear. The samples collected from the younger strata (PM-1, MRW-5, HR-4, HR-5 and HR-6) yielded *Nannoconus* specimens belonging to *N. wintereri* (Fig. 9: 3, 5, 6), *N. infans* (Fig. 9: 4), *N. cf. compressus* (Fig. 9: 7) and *N. sp. A*. These samples can be assigned to the lower part of *N. wintereri* Zone. The upper part of this Zone is not documented in the Wapiennik klippe section. Also, the basal interval of the *N. wintereri* Zone is not detected as the samples belonging to the Boneti Subzone of the *Chitinoidella* Zone have not been found in the studied rock material. According to Wiêtczak (1999), the Tithonian/Berriasian boundary is situated between samples HR-5 and HR-6, that is, at the contact of the Czorsztyn Limestone Formation with the Pieniny Limestone Formation (Fig. 8). The present study revealed that the Tithonian/Berriasian boundary (=J/K boundary) is located higher up in the section above the sample HR-9, which belongs to the uppermost Tithonian. Therefore, the lower part of the Pieniny Limestone Formation 3.5 do 4 m thick was deposited during Late Tithonian time. The base of this formation is correlated with the middle part of Late Tithonian *Crassicollaria* Standard Zone (A2 Subzone in the calpionellid subdivision of Remane, 1964, 1985).

**Kapuśnica I section (K in Fig. 1C)**

This section is located in the Kapuśnica klippe at the dam’s level (Pszczółkowski & Myczyński, 2004). The boundary between the Buwałd Radiolarite Member of the Czajakowa Limestone Formation and the Upszar Limestone Member of the Czorsztyn Limestone Formation is indicated (Fig. 10) 60 cm below the previously assumed location (see Pszczółkowski & Myczyński, 2004, fig. 3). This change is supported by thin sections study of the beds assigned here to the basal interval of the Upszar Limestone Member. Rare specimens assigned to *N. compressus* Bralower et Thierstein, 1989 (Fig. 9: 8, 9) occur in the basal beds of the Upszar Member (Fig. 11). Below the *Nannoconus compressus* Zone, the lowermost Tithonian strata may occur in the topmost part of the Buwałd Radiolarite Member above the bed K-01 (Fig. 11) or, alternatively, there is a hiatus at the boundary of the Czajakowa Radiolarite Fm. and Czorsztyn Limestone Formation in the Kapuśnica I section.

**Gacówka section (G in Fig. 1C)**

In the Gacówka section (Branisko Succession according to Birkenmajer, 1979), the Upszar Limestone Member of the Czorsztyn Limestone Formation is composed of two informal units: (1) layered limestone (uppermost Kimmeridgian–Lower Tithonian) and (2) massive pseudonodular limestone of Late Tithonian age (Fig. 12). In this section, the first nannoconids occur in the Early Tithonian limestones of the Dobeni Subzone (*Chitinoidella* Zone) – Fig. 12 and Fig. 13: 3. The
species *Nannoconus infans* Bralower (Fig. 13: 1, 2) and *N. wintereri* Bralower et Thierstein 1989 appear in the basal interval of the Boneti Subzone. The taxon *N. cf. compressus* (Fig. 13: 4) has been observed in the lower part of the Boneti Subzone. The species *N. wintereri* (Fig. 13: 5) and *N. steinmannii minor* (Fig. 13: 6) occur in the Lower Berriasian limestone of the Pieniny Limestone Formation (Fig. 12). Thus, in the Gacówka section, the Late Tithonian occurrences of *Nannoconus* belong to *N. wintereri* Zone, although strong influence of tectonic deformation does not permit to apply more detailed zonal (*Nannoconus*-based) subdivision of the exposed strata.
Fig. 11. Distribution of nannofossils and calcareous Dinoflagellata cysts at the boundary of the Buwald Radiolarite Member and the Upszar Limestone Member in the Kapuśnica I section.
Fig. 12. *Nannoconus* occurrence in the Tithonian–earliest Berriasian strata, Gacówka section (Branisko Succession, Pieniny Klippen Belt). 1 – radiolarite; 2 – thin-bedded green and red biomicrites; 3 – thick-bedded to massive light grey pseudonodular limestone; 4 – grey micritic limestone; 5 – calcite veins and strongly tectonized strata; 6 – tectonic contact; 7 – taxon occurrence (confirmed); 8 – probable occurrence of a taxon (cf.)
Birkenmajer (1979) presented an outline of lithostratigraphy and a description of this section (= slaughter house at Szczawnica Wyżna). The Palenica Marl Member of the Czorsztyn Limestone Formation (Birkenmajer, 1977) is up to 1.2 m thick (Fig. 14). Nowak (1971, 1976) has assigned this unit to the Early Tithonian Malmica Zone.

In the studied section, the lower boundary of the Palenica Marl Member is tectonically disturbed against the Czajakowa Radiolarite Formation. This Member is subdivided into three informal lithologic units: (1) green shaly marl in the lower part (mz in Fig. 14), (2) red marl in the upper part (mc in Fig. 14), and (3) red nodular marly limestone (Fig. 15). The green marl and a large part of the red marl belong to the Early Tithonian “Pulla-Tithonica” Zone sensu Borza (1984), although speci-
mens of *Carpistomiosphaera borzai* (Nagy, 1966) are also present. Only the uppermost part of the red marl and the marly limestone do contain specimens of *Parastomiosphaera malmica*, so it is assigned here to the Malmica Zone (Fig. 15). This stratigraphical scheme is not exactly the same as the former one (Nowak, 1976, fig. 7), although confirms the (mainly) Early Tithonian age of the Palenica Marl Member (="Aptychi Shales") reported by the cited author.

The specimens of *Nannoconus* have not been found in the lower and middle parts of the Palenica Marl Member. Rare *Watznaueria britannica* (Stradner 1963) Reinhardt 1964 (Fig. 17: 1) and *Watznaueria* sp. occur in the green and red marls (Fig. 16). The *Nannoconus infans* Zone comprises the uppermost part of the Palenica Marl Member and the lowermost interval of the Pieniny Limestone Formation. Aside of the index taxon (Fig. 17: 5, 8-a), the nannofossil assemblage characteristic for this zone contains *Nannoconus* sp. A (Fig. 17: 6, 7), *N. compressus* Bralower et Thierstein, 1989 (Fig. 17: 3), *N. cf. compressus* (Fig. 17: 4) and *Polycostella* (?) sp. (Fig. 17: 8-b). Also, *Conusphaera mexicana* Trejo subsp. *mexicana* Bralower, Monechi et Thierstein, 1989 (Fig. 17: 2) appears in the topmost sample (Gr-4a) collected from the red marl. The first appearance (FAD) of *C. mexicana mexicana* in the Grajcarek section seems to be roughly coeval with the
<table>
<thead>
<tr>
<th>Age</th>
<th>Microfossil Zones After: Rehakova, (2000b) and Borza (1984)</th>
<th>Lithostratigraphic units</th>
<th>Lithic log and samples position</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tithonian</strong></td>
<td>Chitinoidella</td>
<td>Pieniny Limestone Fm.</td>
<td>Still in position</td>
</tr>
<tr>
<td></td>
<td>P. malmica</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Kimmeridgian</strong></td>
<td>“Pulla - Tithonica”</td>
<td></td>
<td></td>
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</tbody>
</table>

- **Fig. 15.** Microfossil stratigraphy of the Tithonian deposits exposed at the Grajcarek section (see Fig. 1C for location): 1 - Green radiolarite (Podmajerz Radiolarite Member); 2 - Red radiolarite (Buwald Radiolarite Member); 3 - Green marl; 4 - Red marl; 5 - Red nodular limestone; 6 - White micritic limestone; 7 - tectonic contacts.
Fig. 16. Nannofossils occurrence and Nannoconus Zones distinguished in the Tithonian deposits of the Grajcarek section. 1–7: see Fig. 15 for explanation.
Fig. 17. Calcareous nannofossils from the Palenica Marl Member (Czorsztyn Limestone Fm.) and the lower part of the Pieniny Limestone Formation in the Grajcarek section: 1 – _Watznaueria britannica_ (Stradner, 1963) Reinhardt, 1964 (distal view), sample Gr-3-1 ("Pulla-Tithonica" Zone, Early Tithonian); 2 – _Conusphaera mexicana_ Trejo _mexicana_ Bralower, Monechi et Thierstein, 1989, sample Gr-4a (Malmica Zone, Early Tithonian); 3 – _Nannoconus compressus_ Bralower et Thierstein, 1989 (longitudinal section), sample Gr-7 (Chitinoidella Zone, ?Early Tithonian); 4 – *N. cf. compressus* Bralower et Thierstein, 1989 (axial section), sample Gr-6 (Malmica Zone, Early Tithonian); 5 – _N. infans_ Bralower, 1989 (longitudinal section), sample Gr-4 (Malmica Zone, Early Tithonian); 6, 7 – _Nannoconus_ sp. A (longitudinal sections), samples Gr-4 and Gr-6 (Malmica Zone, Early Tithonian); 8 – (a) _N. infans_ Bralower, 1989, Chitinoidella Zone, (b) _Polycostella_ (?) sp. (sample Gr-7)
event named “base of (this) taxon” in the basal interval of the *C. mexicana* Zone (NJ-20) and at the top of the CM22n magnetozone (Bralower et al., 1989, fig. 14). The *N. wintereri* Zone is incomplete as its upper part is missing (Fig. 16). Unfortunately, subdivision of the *Chitinoidella* Zone was not achieved in this section (see also Obermajer, 1986), thus the lower boundary of the *N. wintereri* Zone could not be correlated with the corresponding subzone of the *Chitinoidella* Zone. Nevertheless, a change towards an assemblage characterized by more frequent *Nannoconus* specimens is conspicuous. The *N. compressus* Zone was not found in the Grajcarek section. As the lower boundary of the *N. infans* Zone is close (although below) to the top of the red marl, this suggests that the late appearance of *Nannoconus* in this section could be influenced by local paleoceanographic factors.

**Kryta Valley section, Western Tatra Mts (KV in Fig. 1D)**

Stratigraphy of the deposits exposed in this section located in the Kryta Valley, Western Tatra Mountains, was studied by Grabowski & Pszczółkowski (2004, 2006a, b). These Tithonian deposits belong to the Jasenina Formation and consist of limestone with marl interbeds (Fig. 18); their upper part is assigned to the Pośrednie Member of this formation (Pszczółkowski, 2003).

In the Kryta Valley section, the *Nannoconus infans* and *N. wintereri* Zones are correlated with the earliest Late Tithonian Boneti Subzone of the *Chitinoidella* Zone. The species *N. infans* Bralower (Fig. 20: 5, 6) occurs in the lower part of the Boneti Subzone (Fig. 19), whereas *N. wintereri* Bralower et Thierstein (Fig. 20:
appears in the upper part of the studied section, that is, within the Boneti Subzone and continues in the Praetintinnopsella Zone. Specimens of *N. compressus* Bralower et Thierstein 1989 (Fig. 20: 1) and *N. cf. compressus* are present in both above-mentioned *Nannoconus* Zones. However, the upper boundary of the *N. wintereri* Zone is located in the younger limestones not exposed in this section. In contrast with the *N. infans* Zone, nannoconids are more numerous in the lower interval of the *N. wintereri* Zone, equivalent to the upper part of the Late Tithonian Boneti Subzone (Tab. 1). Michalík et al. (2008, 2009) reported that in the Brodno
section (Kýsuca Succession, Pieniny Klippen belt, Slovakia) \textit{Polycostella} Thierstein, 1971, increased in abundance during the Boneti Subzone. The increase in abundance of \textit{Nannoconus} specimens correlates very well with the Mid- to Late Tithonian Nannofossil Calcification Event (NCE) of Bornemann \textit{et al.} (2003), but apparently preceded a change from microgranular chitinoidellid loricas to calcitic (hyaline) calpionellids (Reháková & Michalík, 1993).

\textbf{TITHONIAN \textit{NANNOCONUS} ZONES: THEIR DEFINITION, STRATIGRAPHIC POSITION AND CORRELATION WITH STANDARD NANNOFOSIL ZONATION}

The \textit{Nannoconus}-based zonation proposed earlier (Pszczółkowski, 2006, 2008) and confirmed in this paper (Tab. 1) follows the definition of the Subzones NJK-b and NJK-c of Tavera \textit{et al.} (1994), related to the first appearances of \textit{N. infans} Bralower and \textit{N. wintereri} Bralower et Thierstein, respectively. However, it appears from the data presented herein that the Tithonian biostratigraphic scheme
based on nannoconids needs changes in respect to NJK-a, NJK-b and NJK-c (Tavera et al., 1994). The Subzone NJK-a was based on a presence of *N. compressus* Bralower et Thierstein (Tavera et al., 1994), but the lower boundary of this Subzone was not determined by these authors. According to Bralower et al. (1989), at site 534A the FAD of *N. compressus* occurs within the CM21 magnetozone and (probably) below the *Chitinoidella* Zone (Tab. 1). However, also in the Central Atlantic, Bornemann et al. (2003) have placed this event at the base of the NJ-20B Zone (across the M21/M20 magnetozenal boundary). Also Tremolada et al. (2006) have marked first occurrence (FO) of *Nannoconus* spp. at the CM21–CM20 boundary. In Spain, all the above-mentioned subzones of the NJK Zone (a–c) have been correlated with the Late Tithonian *Durangites* (ammonite) Zone and the lower part of the Jacobi Zone (Tavera et al., 1994). In terms of the calpionellid stratigraphy, these *Nannoconus* subzones corresponded to the calpionellid *Intermedia* Subzone (Tavera et al., 1994; see also Tab. 1). The NJK-c Subzone of Tavera et al. (1994) terminated below the *Crassicollaria/Calpionella* zonal boundary. Therefore, in fact the NJK-d Subzone of Tavera et al. (1994) was not an exact equivalent of NJK-D (=*N. steinmannii minor*) Subzone of Bralower et al. (1989).

In the studied sections from the Pieniny Klippen Belt and the Western Tatra Mts., the *Nannoconus compressus* Zone was identified in the Stare Bystre (Fig. 6) and Kapuśnica I (Fig. 11) sections, only. The stratigraphic position of its lower boundary is probably below the Malmica Zone, whereas the upper boundary is placed within the Malmica Zone (Tab. 1). This first *Nannoconus* assemblage is very poor in taxa and specimens, as well. The *N. infans* Zone occurs in the following sections: Stare Bystre (Fig. 6), Grajcarek (Fig. 16) and Kryta Valley (Fig. 19). Its lower boundary coincides with the upper one of the *N. compressus* Zone and the top of this zone occurs within the *Chitinoidella* Zone (Tab. 1). The nannoconid assemblage of the *N. infans* Zone consists of the following taxa: *N. infans*, *N. compressus* and *N. sp. A*. In the Grajcarek section, *Conusphaera mexicana mexicana* appears (FAD?) within the basal interval of the *N. infans* Zone; as shown in Tab. 1, this position seems to be slightly above the FAD of the taxon as indicated for the Central Atlantic Ocean (Bralower et al., 1989). Therefore, *N. infans* Zone probably correlates with a part of the NJ-20 Zone (*C. mexicana*) and the basal interval of the NJK-A (=*H. noelae*) Subzone of Bralower et al. (1989), although *Nannoconus* species have not been mentioned from the nannofossil assemblage occurring in their *C. mexicana* Zone. Also, this zone may correspond to a lower part of the *Polycostella beckmannii* Subzone (NJ-20B) in the Brodno section (Michalík et al., 2009). In the Kryta Valley section, the Infans/Wintereri zonal boundary is located within the Boneti Subzone (Fig. 19). This location may be correlated with the lower part of the CM20n magnetozone (Grabowski & Pszczółkowski, 2004).

The *N. wintereri* Zone is reported from all the studied sections, except the Kapuśnica I one (Fig. 11). Besides the Kryta Valley section (Fig. 19), its lower boundary is tentatively designated at Stare Bystre (Fig. 6), directly above the base of the Boneti Subzone. However, the Dobeni/Boneti subzonal boundary could not be precisely determined in the Stare Bystre section. The upper boundary of the *N.*
The Zone is located in the uppermost part of the Dursztyn Limestone Formation directly below the sample By-19 (Fig. 6). The nannoconid assemblage consists of *N. wintereri, N. infans, N. compressus, N. sp. A*, and rare *N. globulus minor*. The *N. wintereri* Zone should correspond to the NJK Zone (Bralower et al., 1989) or NJ-20B and NJK-A-C (Bornemann et al., 2003). However, the FAD of *N. wintereri* was placed within the NJK-C Subzone (Bralower et al., 1989) or at the base of NJK-c Subzone (Tavera et al., 1994). Such a high stratigraphic position of this event, corresponding to the uppermost interval of the Late Tithonian *Crassicollaria* Zone (Tab. 1), is not confirmed by the data reported in this study. According to Michalík et al. (2006), *N. wintereri* appears directly above the base of the *Crassicollaria* Zone in the Brodno section (Kýsuca Succession, Pieniny Klippen Belt, Slovakia). In the recent paper on the Brodno section stratigraphy (Michalík et al., 2009, fig. 9), the first occurrence of this taxon is shown within the Upper Tithonian (*Crassicollaria colomi* Subzone), about 0.5 m above the J/K boundary previously designated by Houša et al. (1999).

The *Nannoconus steinmannii minor* Zone was identified in the Stare Bystre (Fig. 6) and Gacówka sections (Fig. 12), whereas the *N. steinmannii steinmannii* Zone occurs in the middle and upper intervals of the Early Berriasian Alpina Subzone (Tab. 1) and continues into the Middle Berriasian *C. elliptica* Subzone (Bralower et al., 1989, 1995; Pszczółkowski & Myczyński, 2004).

**TAXONOMIC REMARKS**

In the studied sections, specimens referred here to *Nannoconus* sp. A occur in the Tithonian strata, which belong to the *N. infans* and *N. wintereri* Zones, mainly. These specimens differ from published descriptions of other species (*N. compressus, N. infans* and *N. wintereri* – Bralower et al., 1989). The specimens assigned to *Nannoconus* sp. A are larger than *N. infans* and do not possess a wide axial canal as is characteristic for *N. wintereri* (Table 2). The cone-shaped *Nannoconus* specimens differ also from rectangular to elongate oval representatives of *N. compressus* (Tab. 2). Specimens shown in Figs 7: 2, 9: 1 and 17: 7 are typical representatives of the taxon *Nannoconus* sp. A. The largest specimens attain dimensions 7 × 7 µm. The relation of the described earliest cone shaped forms to the Early Berriasian *N. steinmannii* Kamptner subsp. minor Deser et Achéritéguy, 1980 is not clear. According to Bralower et al. (1989, fig. 2), the evolutionary lineage consisted of taxa *N. compressus-N. infans-N. wintereri*-*N. steinmannii minor*-N. kamptneri minor-*N. steinmannii steinmannii*. However, Tithonian forms similar to *Nannoconus* sp. A have not been included in this lineage.

**CONCLUSIONS**

In the investigated sections of the Pieniny Klippen Belt (southern Poland) the Early Tithonian *Nannoconus compressus* Zone correlates with the uppermost part of the “Pulla-Tithonica” Zone (Borza, 1984) and lower part of the Malmica Zone. The *N. infans* Zone is equivalent to the upper part of the Malmica Zone and the
lower part of the *Chitinoidella* Zone (Dobeni Subzone and the lowermost interval of the Boneti Subzone). The *N. wintereri* Zone corresponds to the uppermost part of the *Chitinoidella* Zone, the entire *Crassicollaria* Zone and the basal interval of the Berriasian Alpina Subzone. In the Kryta Valley section (Western Tatra Mts), the Infans/Wintereri zonal boundary is located within the Boneti Subzone and is correlated with the lower part of the CM20n magnetozone (Grabowski & Pszczółkowski, 2004). Specimens referred to *Nannoconus* sp. A occur in the studied Tithonian *Nannoconus* Zones; these specimens differ from the published descriptions of all previously established Tithonian species. In the Lower Tithonian limestones *Nannoconus* specimens are scarce, being more numerous in the lower interval of the *N. wintereri* Zone. This increase in abundance of *Nannoconus* correlates with the Mid- to Late Tithonian Nannofossil Calcification Event (NCE) of Bornemann *et al.* (2003).

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**Table 2**

Dimensions and outline of selected Tithonian *Nannoconus* species (after Pszczółkowski, 2008, slightly modified)

<table>
<thead>
<tr>
<th>Taxon</th>
<th>Dimensions</th>
<th>Outline</th>
<th>Source of data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bralower et Thierstein</td>
<td>3–8</td>
<td>2–4</td>
<td>Narrow (common lack of axial canal)</td>
</tr>
<tr>
<td><em>Nannoconus infans</em></td>
<td>1–6</td>
<td>Less than 3</td>
<td>Very narrow</td>
</tr>
<tr>
<td>Bralower</td>
<td></td>
<td></td>
<td>Variable (square, elongate or sausage shaped)</td>
</tr>
<tr>
<td><em>Nannoconus wintereri</em></td>
<td>4–8</td>
<td>4–8</td>
<td>Bowl-shaped</td>
</tr>
<tr>
<td>Bralower et Thierstein</td>
<td></td>
<td></td>
<td>Cone shaped</td>
</tr>
<tr>
<td><em>Nannoconus</em> sp. A</td>
<td>4.5–7</td>
<td>4.5–7</td>
<td>Very narrow</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cone shaped</td>
</tr>
</tbody>
</table>
REFERENCES


Michalík, J., Reháková, D. & Halásová, E., 2006. Stop B3.4 – Brodno – railway station quarry (Fig.


