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CALPIONELLID, NANNOFOSSIL AND CALCAREOUS DINOCYST BIOEVENTS AND INTEGRATED BIOCHRONOLOGY OF THE TITHONIAN TO VALANGINIAN IN THE WESTERN BALKANIDES, BULGARIA

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Abstract: This joint study on calpionellids, calcareous nannofossils and calcareous dinocysts of the Tithonian, Berriasian and Valanginian sediments in the Western Balkanides allowed detailed documentation of the stratigraphic ranges and selection of reliable diagnostic bioevents, within the parallel microfossil successions. The individual zonations based on calpionellids, nannofossils and dinocysts are made more precise, refined and directly correlated to each other. The calpionellid zones and subzones recorded in Bulgaria are widely accepted for the Mediterranean. The proposed nannofossil zonation is considered as a regional one for the Western Balkanides. Ten dinocyst zones are recognized three of them being introduced here: Stomiosphaera wanneri, Colomisphaera conferta and Carpistomiosphaera valanginiana. A number of intrinsic coinciding bioevents between two or all the three planktonic microfossil groups are documented and interpreted related to certain stage and substage boundaries. This approach of direct correlation of three fossil groups enhances the argumentation and resolution of the zonation. It may represent a basis for a reference biochronology of the Tithonian to Valanginian, applicable to various lithologies in the Tethyan Realm.

Key words: Bulgaria, Western Balkanides, Tithonian, Berriasian, Valanginian, integrated biochronology, calpionellids, calcareous nannofossils, calcareous dinocysts.

Introduction and sections studied

The thick and continuous Upper Jurassic and Lower Cretaceous pelagic carbonate sequence outcropping extensively in the area of the West Balkan Mountains and West Fore-Balkan, Bulgaria, provides excellent material for detailed, comprehensive biostratigraphic studies on several planktonic microfossil groups and working out of a joint scale of successive bioevents and integrated zonations.

This study encompasses the individual biostratigraphic results on the following microfossil groups: calpionellids, calcareous nannofossils and calcareous dinocysts (cadosinids and stomiosphaerids) from successions of pelagic nodular, pure micritic and clayey limestones of Tithonian, Berriasian and Valanginian age in the Western Balkanides (West Balkan Mountains and West Fore-Balkan) (Fig. 1). Three formations have been studied: the Gintsi Formation (pink and grey nodular limestones), Glozhene Formation (grey hard micritic limestones) and Salash Formation (alternation of micritic limestones, clayey limestones and marls).

A detailed combined sampling has been carried out of three reference sections — Barlya, Gorno Belotintsi 1 and Gorno Belotintsi 2 (Figs. 2–8). Calpionellids and calcareous dinocysts are determined in thin-sections, and calcareous nannofossils in smear slides. The section of Barlya is located at the northern end of the village of Barlya, Sofia District, very close to the Bulgarian-Yugoslavian border, in the area of the West Balkan Mountains. This section provides an uninterrupted stratigraphic Kimmeridgian to Hauterivian succession. We sampled the uppermost 20 m of the Gintsi Formation, the whole Glozhene Formation (37 m) and the lower part of the Salash Formation (108 m) (Figs. 2, 4, 6).

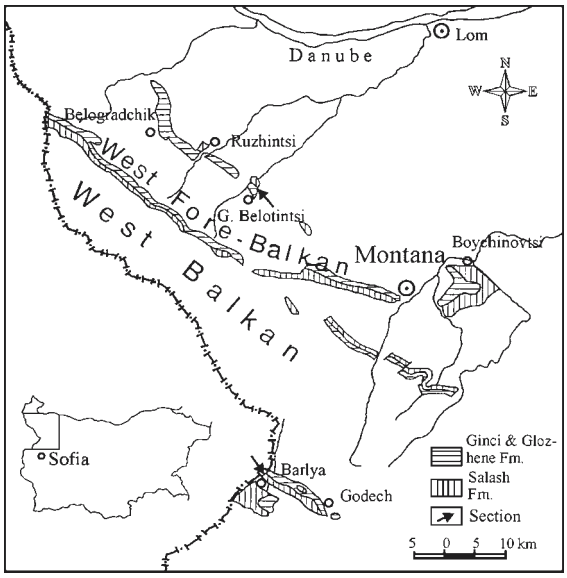

Fig. 1. Outcrops of the Gintsi, Glozhene and Salash Formation in the West Balkan Mountains and West Fore-Balkan and location of the sections studied.

The sections of Gorno Belotintsi 1 and Gorno Belotintsi 2 are situated 3 km to the north of the village of Gorno Belotintsi, Montana District, in the area of the West Fore-Balkan. In Gorno Belotintsi 1 section we sampled the upper part of Gintsi Formation (20 m) and the Glozhene Formation, its thickness there being 240 m, and in Gorno Belotintsi 2 section — the lowest 40 m of the Salash Formation. These two sections are positioned stratigraphically one over another but the lithological transitions between the Glozhene and Salash Formations and the Berriasian-Valanginian boundary are obscured by some absences of exposures.

The calpionellids were studied by I. Lakova, calcareous nannofossils by K. Stoykova and calcareous dinocysts by D. Ivanova.

Calpionellids

In the last four decades, the taxonomic and biostratigraphic studies on calpionellids proved that these planktonic microfossils are essential for the fine division, precise dating and reliable long-distance correlation of Middle Tithonian to Valanginian pelagic carbonates throughout the Mediterranean Realm. The advantages of the calpionellids in biostratigraphy are their relatively rapid evolution consisting of distinguished steps, the unequivocal succession of numerous bioevents (first and last occurrences, phyletic transitions and dramatic increases in abundance) which are used to define the boundaries of 7 interval-zones and total-range zones and at least 12 interval subzones, as well as the common geographical distribution, the lack of provincialism and quantitative abundance.

The originally proposed calpionellid zonal schemes by Remane (1971) and Alleman et al. (1971) were progressively refined, divided into subzones, completed and the criteria of placing the boundaries were specified (Pop 1974, 1976; Borza 1984; Remane et al. 1986; Trejo 1980; Altiner & Özkan 1991; Lakova 1993). Previously, Tithonian and Berriasian calpionellids of the Western Balkanides were studied by Bakalova-Ivanova (1986). We apply here a slightly modified version (Lakova & Stoyanova 1997) of the zonal and subzonal subdivisions by Pop (1994, 1997) and Reháková & Michalík (1997) which differs significantly in terms of subzones from Blau & Grün's (1997) zonation.

Middle and Late Tithonian

Chitinoidella Zone

The first occurrence (FO) of *Chitinoidella dobeni* and related species (*Chitinoidella colomi, Chitinoidella tithonica, Chitinoidella slovenica*) which are the first representatives of the family Codonellidae with microgranular wall indicate the base of the Chitinoidella Zone. This level coincides with the Lower/Middle Tithonian boundary. The zone is divided into two subzones — Chitinoidella dobeni and Chitinoidella boneti, the base of the latter being marked by the FO of *Chitinoidella boneti* (Grandesso 1977; Borza 1984).

Praetintinnopsella Zone

The Praetintinnopsella Zone is defined between the FO of *Praetintinnopsella andrusovi* and the FO of representatives of the family Calpionellidae with hyaline calcite wall (Grandesso 1977). This zone corresponds to the Middle/Upper Tithonian boundary interval.

Crassicollaria Zone

The standard Crassicollaria Zone is restricted between the FOs of calpionellids with hyaline wall and the explosion of *Calpionella alpina*. In most of the sections studied elsewhere in the West Balkan Mountains three species appear simultaneously at the lower boundary of the zone — *Tintinnopsella carpathica, Tintinnopsella remanei* and *Crassicollaria intermedia*. The Crassicollaria Zone corresponds to the Late Tithonian.

There is no agreement on the subzonal division of this zone. We follow the bipartite division proposed at the Sümeg Meeting (Remane et al. 1986), the name of the upper "Intermedia" Subzone being replaced by "Crassicollaria massutiniana" because of the controversial and confusing use of the "Intermedia" Subzone. The base of the Crassicollaria massutiniana Subzone is marked by the FO of *Calpionella grandalpina*, i.e. the large-sized elongated Tithonian form of *Calpionella alpina* s.l.

There is, indeed, a potential to define a third, uppermost subzone within the Crassicollaria Zone on the basis of the FO of *Crassicollaria brevis*, which is usually later than the FO of *Calpionella grandalpina*. We do not accept, however, the "Colomi" Subzone erected by Pop (1994) and Reháková & Michalík (1997) since our studies have proved that *Crassicollaria colomi* occurs only in the lower part of the overlaying Calpionella Zone and has nothing to do with the Crassicolaria Zone. An additional criterion to determine the upper boundary of the Crassicollaria Zone is the last occurrence (LO) of *Calpionella elliptalpina*, the so-called "homeomorph of *Calpionella elliptica*". This event coincides with the explosion of *C. alpina* (Figs. 2, 3).

Berriasian

Calpionella Zone

The Standard Calpionella Zone is defined between two easily determinable biostratigraphic events — the explosion of *Calpionella alpina* s.s., i.e. the medium-sized spherical form of *C. alpina* s.l., and the FO of *Calpionellopsis simplex*. The boundary between the Crassicollaria and Calpionella zones was recommended as boundary between the Tithonian and Berriasian stages at the Lyon–Neu Châttel Colloquium in 1973. In terms of ammonite zones and substages, the Calpionella Zone corresponds to the Berriasella jacobi Zone (Early Berriasian) + Tirnovella occitanica Zone (Middle Berriasian).

The zone has been divided into three subzones. Within the Calpionella Zone, two successive bioevents are used for def-

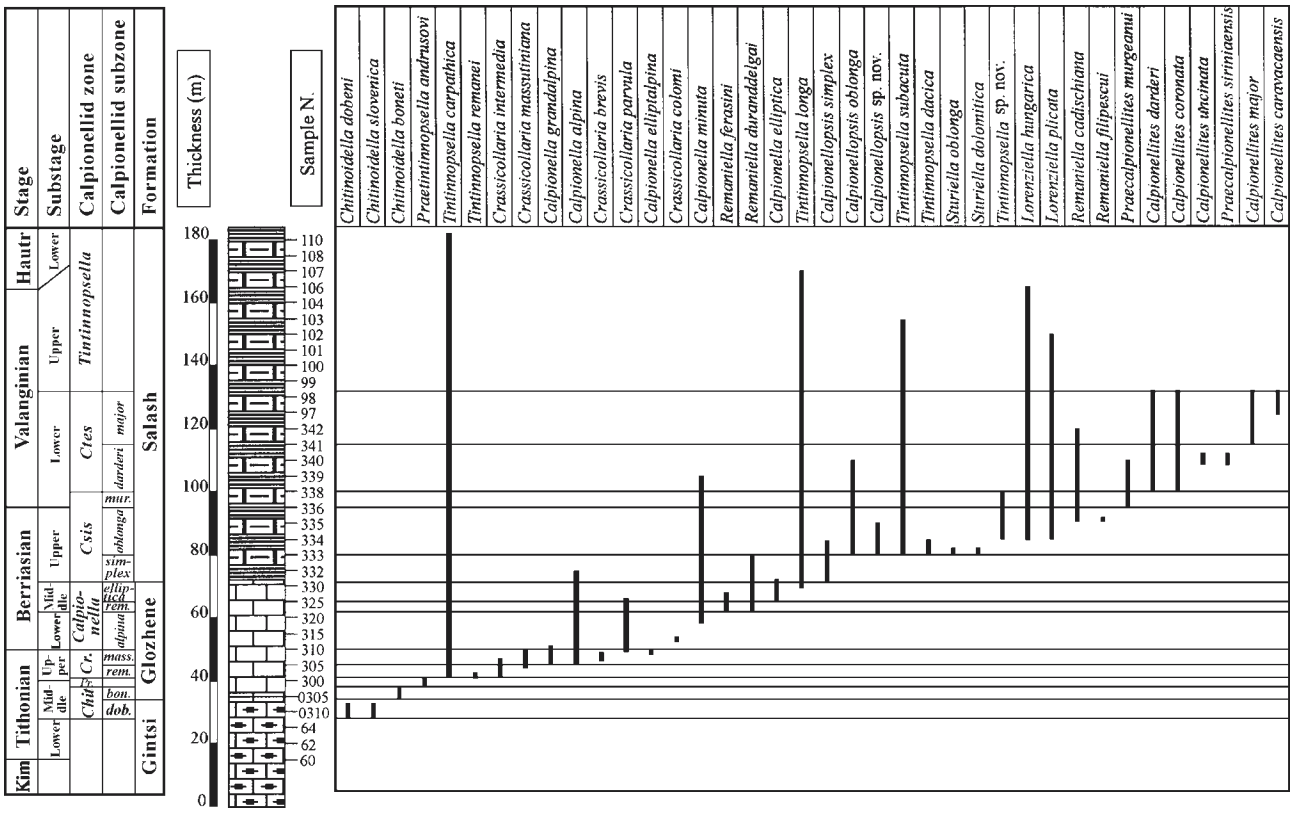

Fig. 2. Range chart of calpionellids and zonation of Barlya section, West Balkan Mountains.

inition of subzones. The FOs of *Remaniella ferasini* and/or *Remaniella duranddelgai* indicate the lower boundary of Remaniella ferasini Subzone, and the FO of *Calpionella elliptica* — the base of Calpionella elliptica Subzone. In addition, we documented in many sections another two bioevents within the Calpionella alpina Subzone which offer a tool for further refining the division of the Early Berriasian. These are the FO of *Crassicollaria colomi* in the lower portion and the FO of *Calpionella minuta*, the so-called "small degenerative Berriasian form of *Calpionella alpina* s.l.", in the upper half of the Calpionella alpina Subzone (Fig. 3). In the uppermost part of the Calpionella Zone, within the Calpionella elliptica Subzone, the FO of *Tintinnopsella longa* enables the definition of a forth subzone, the Tintinnopsella longa Subzone, as proposed by Pop (1994) but this subzone is still not widely accepted.

Calpionellopsis Zone

The Standard Calpionellopsis Zone is defined between the FOs of *Calpionellopsis simplex* and *Calpionellites darderi*. It is divided into three subzones: Calpionellopsis simplex, Calpionellopsis oblonga and Praecalpionellites murgeanui. The lower boundary of the Calpionellopsis oblonga Subzone is placed at the FO of *Calpionellopsis oblonga*, and the base of the Praecalpionellites murgeanui Subzone — at the FO of *Praecalpionellites murgeanui*.

The Calpionellopsis Zone coincides totally with the ammonite Fauriella boissieri Zone (Late Berriasian) according to Blau & Grün (1997) and Bulot (1996). The cited authors changed the definition of the lower boundary of the Valanginian at the base of the ammonite "Pertransiens" Zone. However, Pop (1994, 1997) followed the classical definition of the base of the Valanginian at the lower boundary of the ammonite "Otopeta" Zone; in this case the uppermost Praecalpionellites murgeanui Subzone of the Calpionellopsis Zone belongs to the basal part of the Valanginian.

Within the Calpionellopsis oblonga Subzone the diversity of calpionellid species reached its culmination thus enabling a recognition of additional bioevents. In the section of Barlya, the successive FOs of *Calpionellopsis oblonga*, *Lorenziella hungarica* and/or *Lorenziella plicata* and *Remaniella filipescui* are documented. This series of successive bioevents may represent an additional tool for finer subdivision and correlations.

Valanginian

Calpionellites Zone

The Standard Calpionellites Zone is a total-range zone of the genus *Calpionellites*. The FO of *Calpionellites darderi* is the criterion for its lower boundary, whereas the LO of species of genus *Calpionellites* (*Calpionellites coronata, Calpionellites major, Calpionellites caravacaensis*) indicates the upper boundary. The zone is divided into two subzones — the Calpionellites darderi Subzone and Calpionellites major

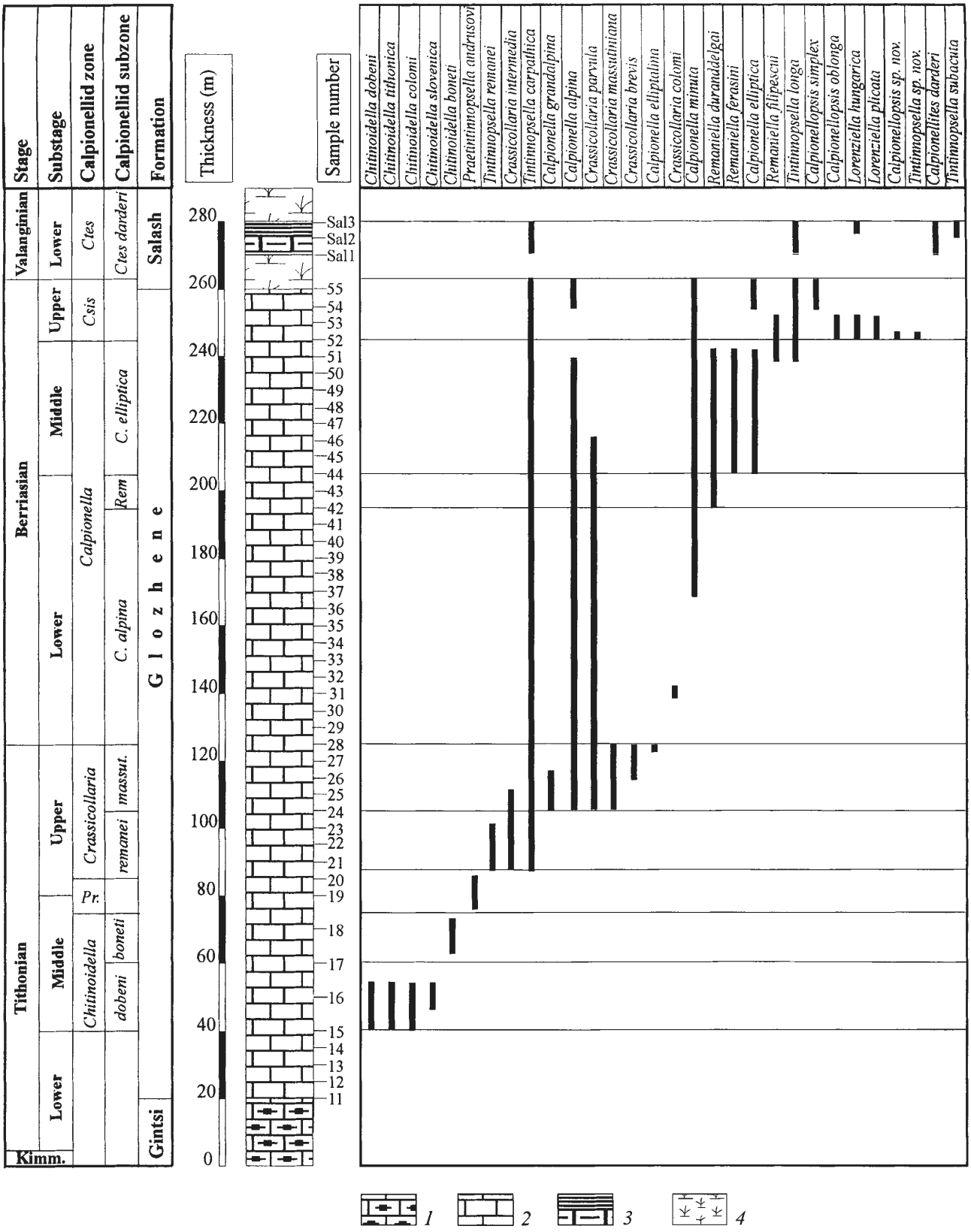

Fig. 3. Range chart of calpionellids and zonation of Gorno Belotintsi 1 section, West Fore-Balkan: *1* — nodular limestones (Gintsi Formation); *2* — micritic and/or intraclastic limestones (Glozhene Formation); *3* — marly limestones and marls (Salash Formation); *4* — no exposures.

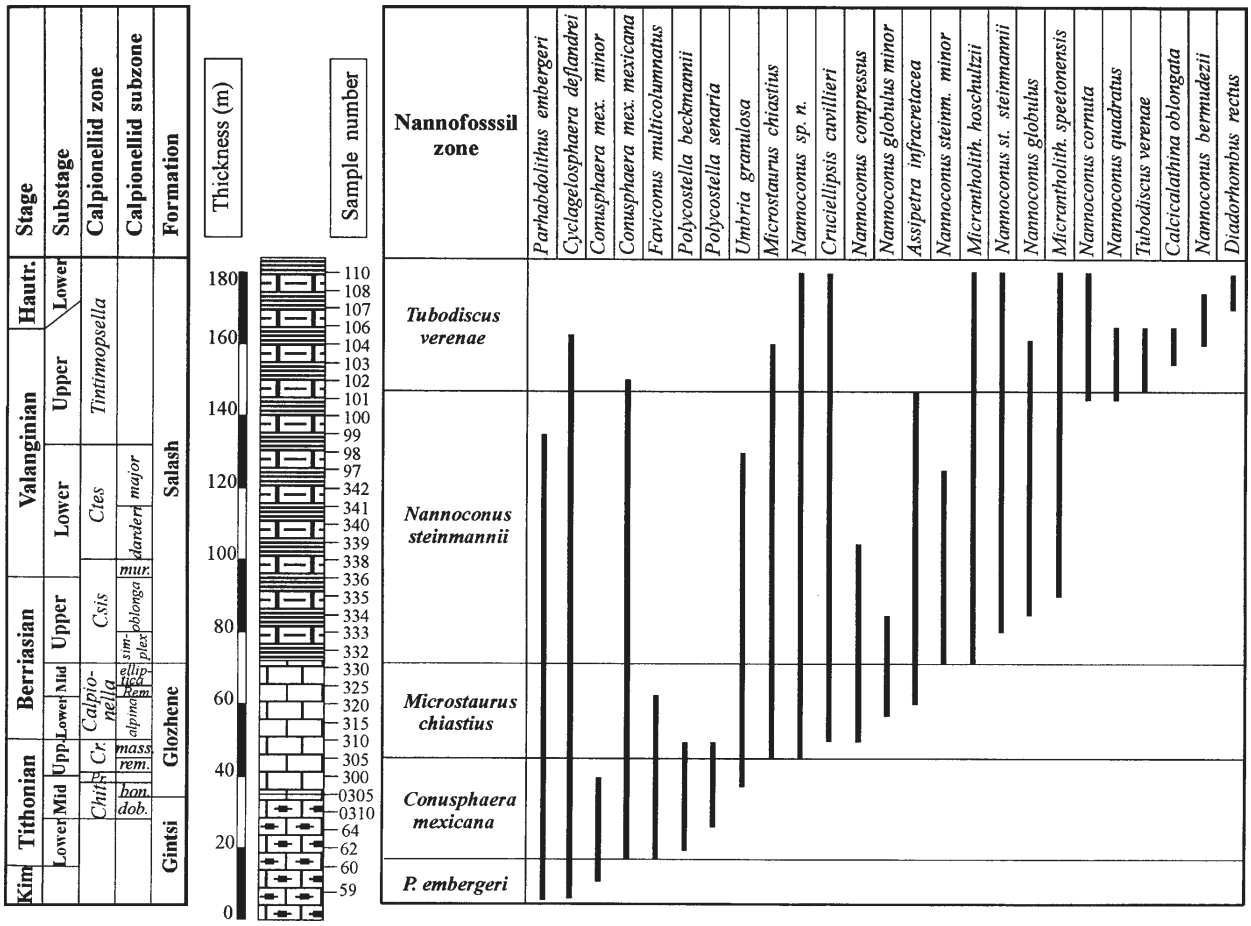

Fig. 4. Range chart of calcareous nannofossils and zonation of Barlya section, West Balkan Mountains.

Subzone, as proposed by Pop (1994) and widely accepted and confirmed in many areas of the Mediterranean Bioprovince. The lower boundary of the Calpionellites major Subzone is placed at the FO of *Calpionellites major*.

The Calpionellites Zone corresponds to the ammonite "Pertransiens" and "Campylotoxum" zones (Early Valanginian except its base).

We have also documented the FO of *Calpionellites coronata* within the Calpionellites darderi Subzone, as well as the FO of *Calpionellites caravacaensis* within the Calpionellites major Subzone (Fig. 8). These two bioevents may be used for further subdivision of the Calpionellites Zone.

Tintinnopsella Zone

The disappearance of genus *Calpionellites* at the Early/Late Valanginian boundary marks a significant decline of calpionellids in both diversity and abundance. After this event, the calpionellid associations consist only of a small number of species of the genera *Tintinnopsella* and *Lorenziella*. The uppermost Tintinnopsella Zone is defined between the LO of *Calpionellites* and the total extinction of calpionellids.

This zone corresponds to the Late Valanginian and to a great part of the Hauterivian, too, according to Pop (1994) and Reháková (1995). In the Western Balkanides, only the Late Valanginian part of the Tintinnopsella Zone has been studied so far. In this lower part, the successive LOs of *Lorenziella hungarica*, *Lorenziella plicata* and *Tintinnopsella longa* represent a potential for definition of subzones.

Calcareous nannofossils

Calcareous nannofossil studies of the Tithonian–Valanginian interval in Bulgaria have been done since 1995. The first work does not appear to have reached a satisfying degree of biostratigraphic resolution (Stoykova 1995). Detailed nannofossil studies both in the Tethyan and Boreal Bioprovinces were done by Thierstein (1971, 1973, 1976) and Roth (1983). Recently, Bralower et al. (1989) and Gardin & Manivit (1993) published refined nannofossil biostratigraphy for this interval (Jurassic–Cretaceous). In conclusion, there is no one widely accepted nannofossil scheme yet. In this work we propose five calcareous nannofossil biozones for the Kimmeridgian–Valanginian interval considered as a regional zonation for the area of the Western Balkanides. This zonation is comparable to some extent to the zonal schemes mentioned above.

The main advantage of the present joint study is the direct correlation of the recorded nannofossil events with calpi-

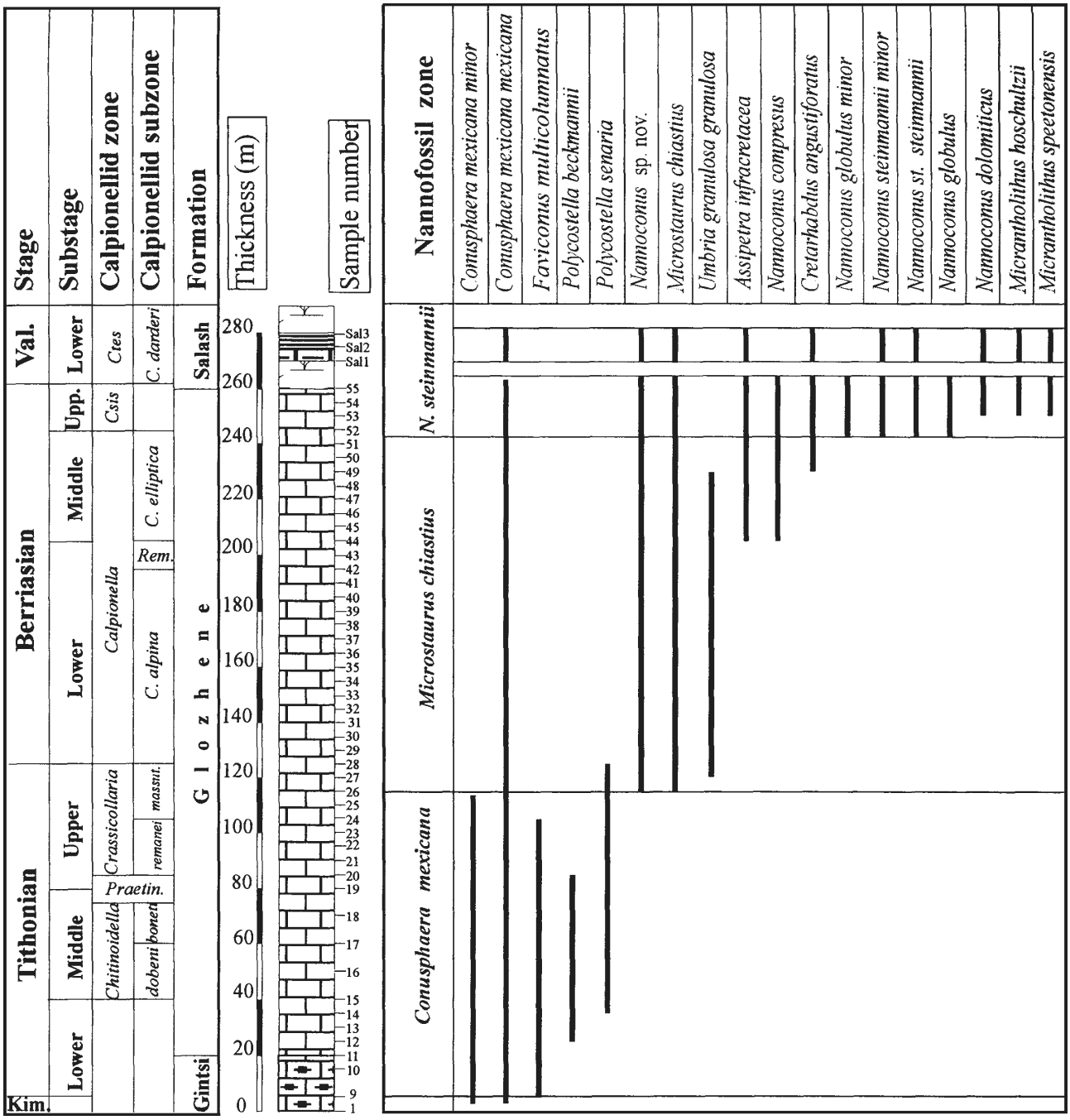

Fig. 5. Range chart of calcareous nannofossils and zonation of Gorno Belotintsi 1 section, West Fore-Balkan (for legend see Fig. 3).

onellid and calcareous dinocyst ones. The samples originating from the section of Barlya yielded relatively diverse and moderately well preserved nannofloras (Fig. 4), whereas in the Gorno Belotintsi sections the assemblages are less diverse and preservation is poorer (Figs. 5, 8). Taking into account these preservation problems affecting nannofossil occurrence we have compiled a series of nannofossil bioevents (Fig. 9).

When selecting events for zonation, we attempted to choose the most reliable, clearly distinctive and repeatable ones in all sections. Bioevents within the zones are considered of less biostratigraphic importance because they are not recognizable in each section.

The zonation proposed here consists of five interval-zones based on successive FOs of the index-species, spanning the Late Kimmeridgian to Valanginian interval: Parhabdolithus embergeri Zone (Late Kimmeridgian), Conusphaera mexicana Zone (Early to Late Tithonian), Microstaurus chiastius Zone (Latest Tithonian–Early and Middle Berriasian), Nannoconus steinmannii Zone (Late Berriasian–Early Valanginian) and Tubodiscus verenae Zone (Late Valanginian).

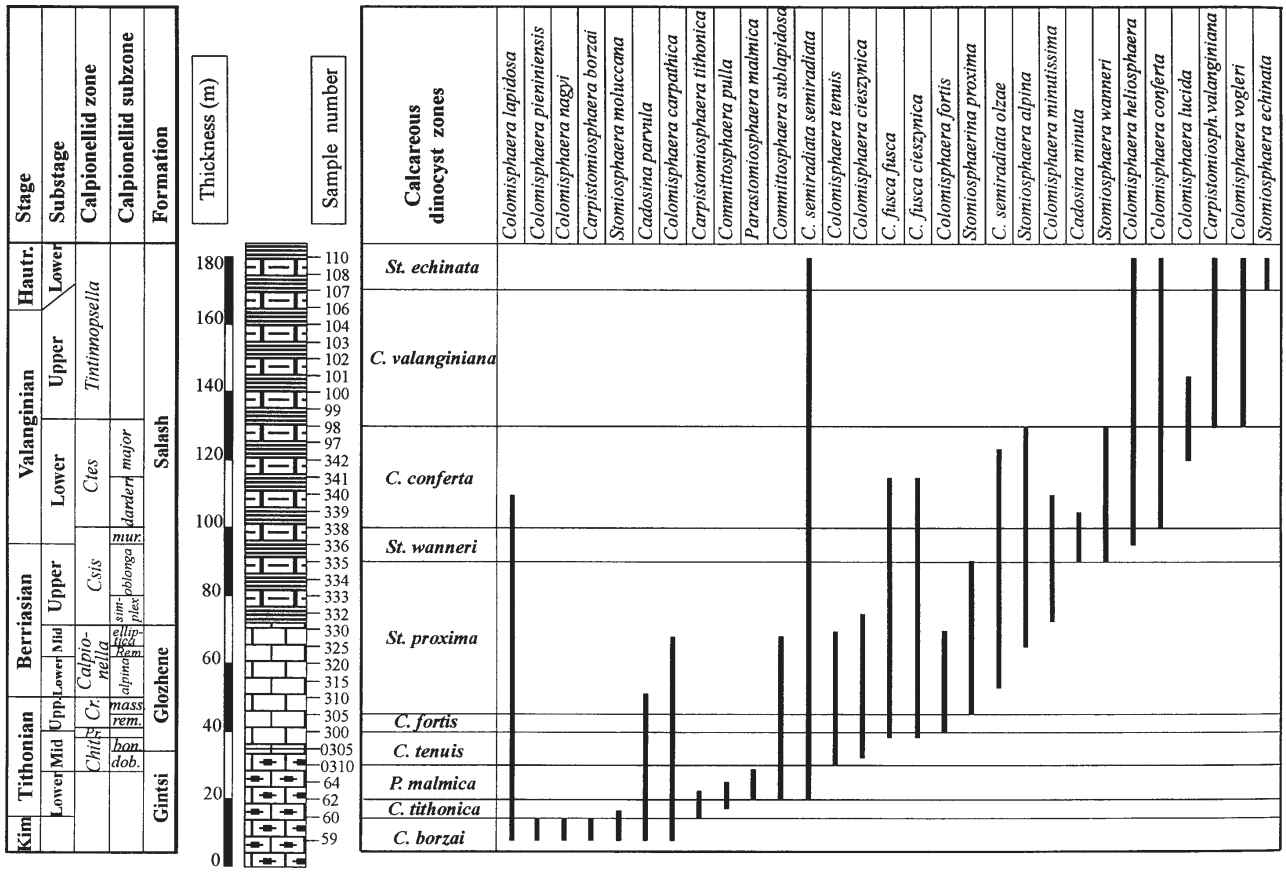

Fig. 6. Range chart of calcareous dinocysts and zonation of Barlya section, West Balkan Mountains.

Late Kimmeridgian

Only the uppermost part of the Kimmeridgian is studied in this work.

Parhabdolithus embergeri Zone

The zone is defined as an interval between the FO of *Parhabdolithus embergeri* and the FO of *Conusphaera mexicana mexicana.* The nannofossil assemblages of this zone are of low diversity and are dominated by *Ellipsagelosphaera* and *Cyclagelosphaera* representatives. The FO of *Conusphaera mexicana minor,* the immediate precursor of *Conusphaera mexicana mexicana,* is documented within this zone in the section of Barlya (Fig. 4).

Tithonian

Conusphaera mexicana mexicana Zone

The zone is regarded as an interval between two clearly determinable bioevents: the FO of *Conusphaera mexicana mexicana* at the beginning of Tithonian and the FO of *Microstaurus chiastius* in the Late Tithonian. In addition, the FO of *Faviconus multicolumnatus* is another reliable event, approximating to the base of this zone (Figs. 4, 5). The nannofossil assemblages change significantly starting from the base of this zone. They are dominated by *Conusphaera mexicana mexicana, Conusphaera mexicana minor* and ellipsagelosphaerids. In the lower part of the zone, the stepwise FOs of *Polycostella beckmannii* and *Polycostella senaria* are recorded (Fig. 4). The FO of *Umbria granulosa* in the upper part of this zone requires further specification.

Berriasian

Microstaurus chiastius Zone

The interval from the FO of *Microstaurus chiastius* to the FO of *Nannoconus steinmannii.* The zone equates to the topmost Tithonian and Early and Middle Berriasian. The FO of *Microstaurus chiastius* at the base of the zone is a suitable diagnostic event, occurring in all the sections studied (Figs. 4, 5).

Within this zone, a succession of first occurrences is observed, some of them representing the early evolution of the nannoconids group: *Nannoconus* sp.n., *N. compressus, N. globulus minor.* The last occurrence of *Polycostella beckmannii* is a less reliable event, but it could also be helpful and needs further elucidation. *Cretarhabdus angustiforatus*, another commonly used marker-species has its FO restricted at the middle of the Calpionella elliptica calpionellid zone.

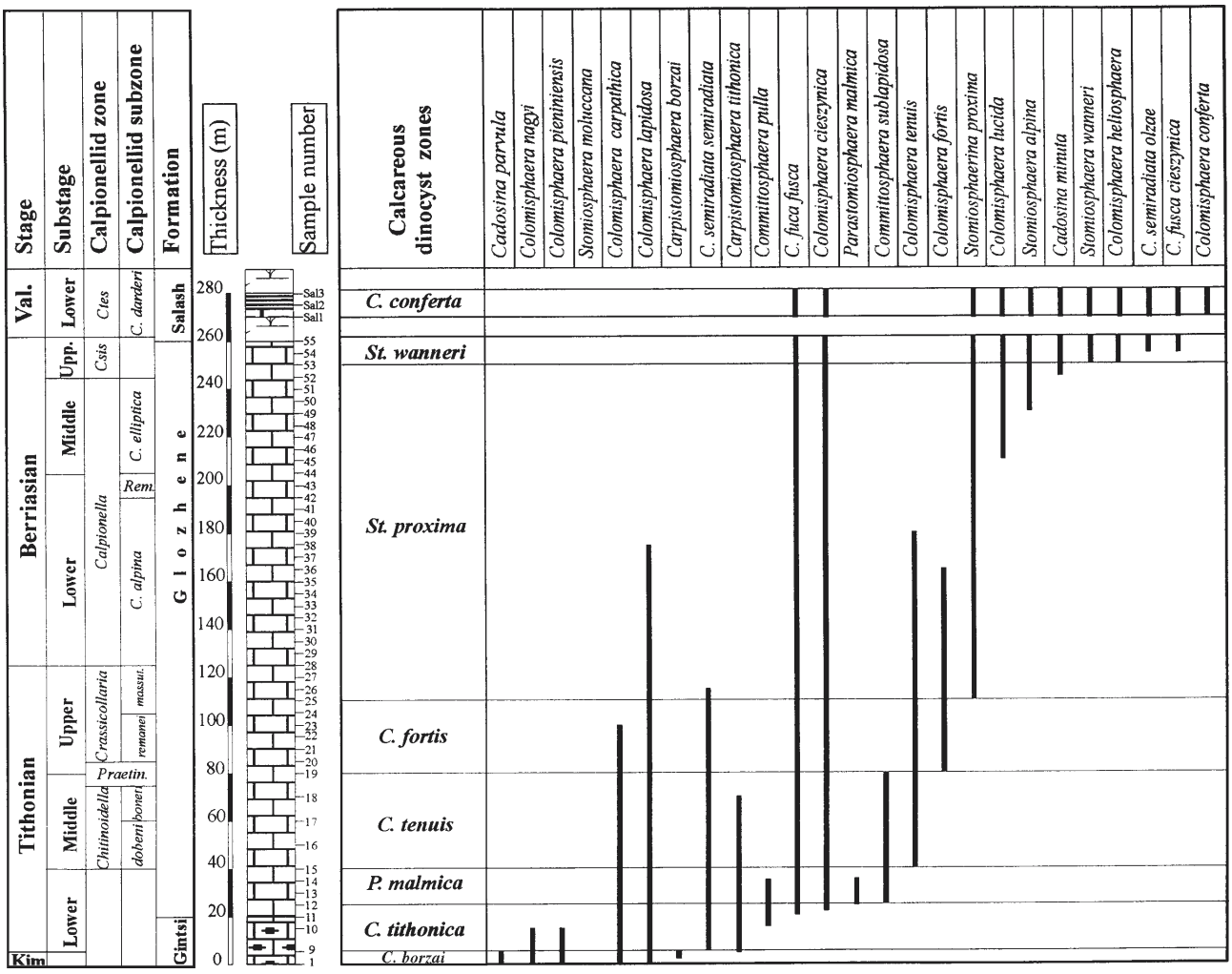

Fig. 7. Range chart of calcareous dinocysts and zonation of Gorno Belotintsi 1 section, West Fore-Balkan (for legend see Fig. 3).

Nannoconus steinmannii Zone

This zone is considered to be an interval between the FOs of *Nannoconus steinmannii minor* and *Tubodiscus verenae.* Nannoconids are the major dominant component of the assemblages. The base of this zone corresponds to the explosion in nannoconid abundance, a prominent broadly recognizable event (Figs. 4, 5).

It should be noted that the FO of *Micrantholithus speetonensis* is recorded in the lower part of the zone. *Micrantholithus speetonensis* is usually regarded as an Late Valanginian Boreal marker-species. Recently, Gardin (in Bulot 1996) has shown its FO during the Late Berriasian and earliest Valanginian in the NW Tethyan basin. These data are consistent to our finds (Figs. 4, 5).

The nannofossil data in the present study enable a good biostratigraphic resolution in the middle and upper part of this zone. Therefore, it should be further examined in other, more suitable localities.

Late Valanginian

Tubodiscus verenae Zone

The base of this zone is marked by the FO of *Tubodiscus verenae* — an event which approximates to the Lower/Upper Valanginian boundary in terms of calpionellids. A couple of additional first co-occurrences makes the base of the zone easily determinable: the FOs of *Nannoconus cornuta, N. quadratus*, etc. Other stratigraphically important species appearing within this zones are *Calcicalathina oblongata, Nannoconus bermudezii* and *Diadorhombus rectus* (Fig. 4).

Calcareous dinocysts

The interest in the study of calcisphaerids concentrated in the past mainly on its biostratigraphic implication, was directed in the last 15–20 years to another aspect — elucidation of

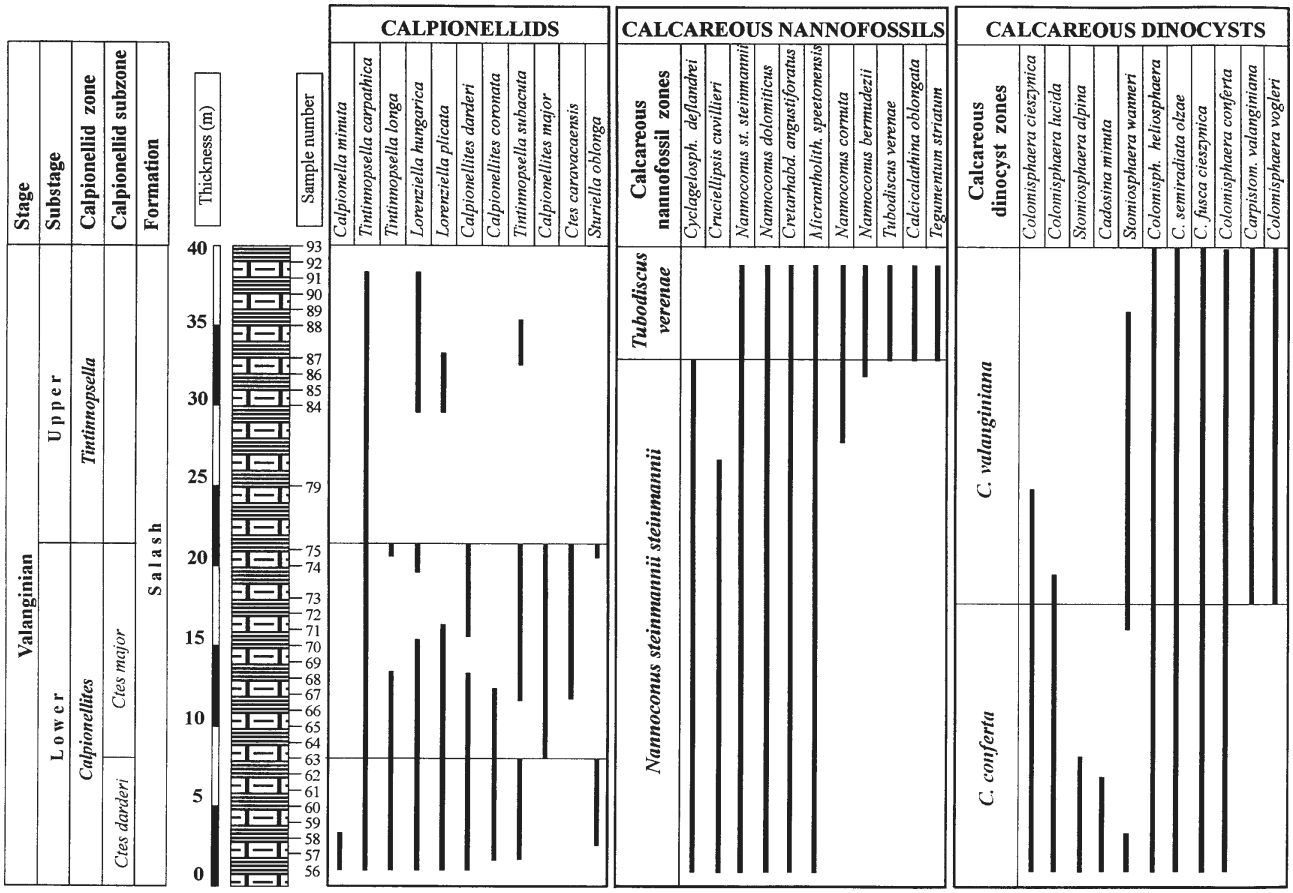

Fig. 8. Range chart and zonations of calpionellids, calcareous nannofossils and calcareous dinocysts of Gorno Belotintsi 2 section, West Fore-Balkan.

their biological affinities and taxonomical identification of species belonging to the calcareous dinocysts. In spite of the new approaches and tendencies in the study of calcisphaerids, their stratigraphic importance for the Late Kimmeridgian–Early Valanginian time interval remains significant.

On the basis of the succession of vertical ranges of cadosinid and stomiosphaerid species proved in several sections, Nowak (1968) proposed 6 zones from the Late Kimmeridgian to the Hauterivian: Moluccana, Pulla, Malmica, Cieszynica-carpathica, Minutissima-carpathica and Echinata. Later on, Nowak (1976) revised his first zonation. Further contributions to the biostratigraphy of calcisphaerids were made by Borza (1969, 1984), Borza & Michalík (1986), Řehánek (1992), Řehánek & Heliasz (1993), Řehánek & Cecca (1993), Vašíček et al. (1994).

The detailed and parallel microfossil studies carried out on the Tithonian to Valanginian of the Western Balkanides allow a series of successive FOs of calcareous dinocyst species to be recorded (Figs. 6, 7). These FOs are directly correlated to the calpionellid events and to the stratigraphic time scale. The calcareous dinocyst zonation here recorded consists of 10 interval-zones, the bases of all being defined by the FO of index-species (Fig. 9). The following dinocyst zones previously proposed by different authors are confirmed in the West Balkan and West Fore-Balkan: Carpistomiosphaera borzai, Carpistomiosphaera tithonica, Parastomiosphaera malmica, Colomisphaera tenuis, Colomisphaera fortis, Stomiosphaerina proxima and Stomiosphaera echinata. In this study, the definition of their bases and the chronostratigraphic assignment of these zone are specified. Three new dinocyst interval-zones are introduced within the Uppermost Berriasian–Valanginian interval: Stomiosphaera wanneri, Colomisphaera conferta and Carpistomiosphaera valanginiana zones (Figs. 6, 7, 8).

Late Kimmeridgian

Carpistomiosphaera borzai Zone

The lower boundary is defined at the FO of *Carpistomiosphaera borzai.* The index-species is associated with *Cadosina parvula, Colomisphaera pieniniensis, C. lapidosa* and *C. carpathica.* The zone corresponds partly to Parhabdolithus embergeri nannofossil zone and to the Late Kimmeridgian (Figs. 6, 7).

Tithonian

Carpistomiosphaera tithonica Zone

The FO of *Carpistomiosphaera tithonica* at the base of the Tithonian marks the lower boundary of this zone. The suc-

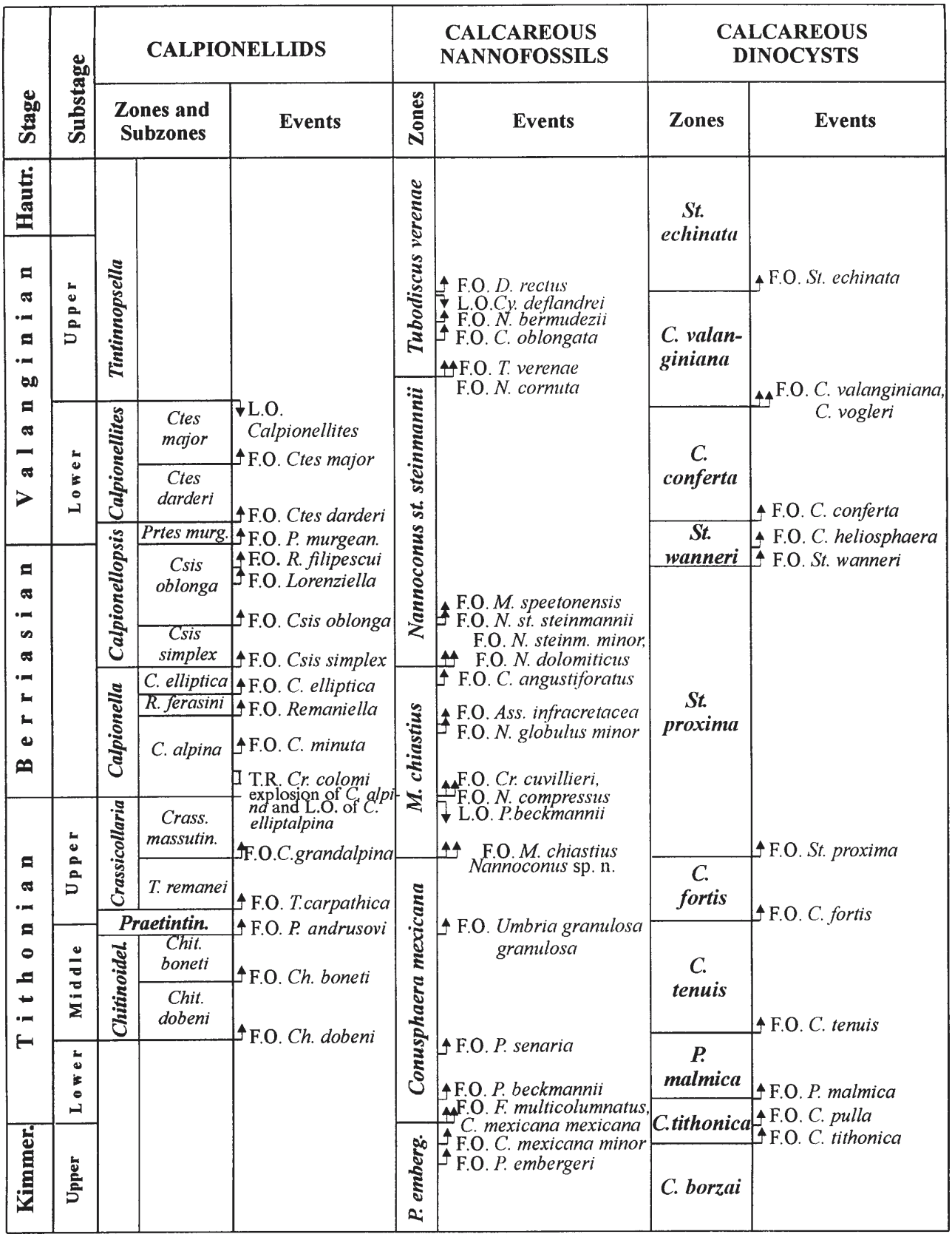

Fig. 9. Bioevents and integrated zonations of the Tithonian, Berriasian and Valanginian of the Western Balkanides.

cessive first occurrences of *Cadosina semiradiata semiradiata, C. fusca fusca* and *Committosphaera pulla* are documented within the zone. The Carpistomiosphaera tithonica Zone spans the Kimmeridgian-Tithonian boundary interval (Fig. 7).

Parastomiosphaera malmica Zone

The base of this zone is defined at the FO of *Parastomiosphaera malmica*. The zone corresponds to the Early Tithonian. Its upper boundary is placed in the basal part of the calpionellid Chitinoidella Zone thus the top of Parastomiophaera malmica Zone slightly overlaps the very base of Chitinoidella Zone (Figs. 6, 7).

Colomisphaera tenuis Zone

The FO of the index-species *Colomisphaera tenuis* marks the base of this zone. Colomisphaera tenuis Zone corresponds exactly to the calpionellid Chitinoidella Zone (Middle Tithonian). Our combined calpionellid and dinocyst studies proved the coeval FOs of *Chitinoidella dobeni* and *Colomisphaera tenuis* (Figs. 6, 7).

Colomisphaera fortis Zone

The lower boundary of this zone is defined by the FO of *Colomisphaera fortis* in the middle of the Praetintinnopsella Zone. Within the Colomisphaera fortis Zone, the abundance and diversity of calcareous dinocysts significantly decreased. This zone coincides with the upper part of the calpionellid Praetintinnopsella Zone and the Tintinnopsella remanei Subzone of Crassicollaria Zone (earliest Late Tithonian) (Figs. 6, 7).

Berriasian

Stomiosphaerina proxima Zone

The lower boundary of this zone is defined by the FO of *Stomiosphaerina proxima* an event coinciding with the FOs of *Calpionella grandalpina* and *Microstaurus chiastius* in the middle of the Upper Tithonian (Fig. 9). It suggests that Řehánek's (1992) proposal to place the Tithonian-Berriasian boundary at the FO of *Stomiosphaerina proxima* is not applicable. This is a relatively longer-ranging zone which is comparable to the sum of the calpionellid Crassicollaria massutiniana, Calpionella alpina, Remaniella ferasini, Calpionella elliptica, Calpionellopsis simplex subzones and the lower part of the Calpionellopsis oblonga Subzone (latest Late Tithonian and the whole Berriasian except its very top) (Figs. 6, 7).

Stomiosphaera wanneri Zone

The FO of the index-species *Stomiosphaera wanneri* marks the base of this zone and the FO of *Colomisphaera conferta* — its top. The zone is here proposed as a new one. Within the Stomiosphaera wanneri Zone, *Colomisphaera heliosphaera* makes its FO. This zone corresponds approximately to the upper third of the calpionellid Calpionellopsis oblonga Subzone and the Praecalpionellites murgeanui Subzone (latest Berriasian and Early Valanginian) (Figs. 6, 7).

Valanginian

Colomisphaera conferta Zone

This zone is the interval between the FO of *Colomisphaera conferta* and the FOs of *Carpistomiosphaera valanginiana* and/or *Colomisphaera vogleri*. The zone is introduced in this paper. In terms of calpionellid zonation, the Colomisphaera conferta Zone corresponds to the calpionellid Calpionellites darderi and Calpionellites major subzones (Early Valanginian) (Figs. 6, 7, 8).

Carpistomiosphaera valanginiana Zone

The FO of the index-species *Carpistomiosphaera valanginiana* defines the lower boundary of the zone. The zone is first defined in this study. It is comparable to the calpionellid Tintinnopsella Zone in its Late Valanginian part (Figs. 6, 8)

Stomiosphaera echinata Zone

The FO of the index-species marks the lower boundary of this zone, whereas the upper boundary is still not determined. The studied part of Stomiosphaera echinata Zone is tentatively assigned to the Late Valanginian and Early Hauterivian on the basis of diagnostic ammonite finds in the topmost part of the section of Barlya (Fig. 6).

Microfossil bioevents, zonations and chronostratigraphic subdivision

The chronostratigraphic assignment of the calpionellid zones from Chitinoidella to Tintinnopsella (Middle Tithonian–Hauterivian) is given according to Pop (1994) and the bioevents and zonations on nannofossils and calcareous dinocysts are correlated to those on calpionellids (Fig. 9). The Kimmeridgian-Tithonian boundary is fixed on the basis of diagnostic FO of nannofossil and calcareous dinocyst species.

The FOs of nannofossils *Faviconus multicolumnatus* and *Conusphaera mexicana mexicana* (the lower boundary of Conusphaera mexicana nannofossil zone) and the simultaneous FO of dinocyst species *Committosphaera pulla* in the middle portion of Carpistomiosphaera tithonica dinocyst zone mark the Kimmeridgian-Tithonian boundary (Figs. 4, 6).

At the Lower/Middle Tithonian boundary, the almost coeval first occurrences of the calpionellid *Chitinoidella dobeni* and dinocyst *Colomisphaera tenuis* are documented, thus determining the bases of Chitinoidella dobeni calpionellid subzone and Colomisphaera tenuis dinocyst zone, respec-

tively. Later in the Tithonian, the FO of *Praetintinnopsella andrusovi* (i.e. the base of Praetintinnopsella calpionellid zone) coincides with the FO of the nannofossil *Umbria granulosa granulosa* close to the Middle/Upper Tithonian boundary. Within the Late Tithonian (Crassicollaria Zone) there are a clearly documented simultaneous FOs of representatives of calpionellides, nannofossils and dinocysts: *Calpionella grandalpina, Microstaurus chiastius, Nannoconus* sp.n., *Stomiosphaerina proxima*. This gives ground to define the coinciding lower boundaries of three biostratigraphic units: Crassicollaria massutiniana calpionellid subzone, Microstaurus chiastius nannofossil zone and Stomiosphaerina proxima dinocyst zone (Fig. 9).

The Tithonian/Berriasian boundary is easily determinated in terms of calpionellids at the base of the Calpionella Zone on the explosion of *Calpionella alpina* and the LO of *C. elliptalpina*, events occurring together with the FOs of nannofossil species *Cruciellipsis cuvillieri* and *Nannoconus compressus* (Figs. 2, 4).

Another coinciding microfossil events to be mentioned are the FOs of calpionellid *Calpionellopsis simplex* (base of the Calpionellopsis Zone) and the nannofossils *Nannoconus steinmannii minor* and *N. dolomiticus* (base of the *N. steinmannii* nannofossil zone). The base of Calpionellopsis Zone corresponds to the boundary between the T. occitanica and F. boissieri ammonite zones commonly regarded as Middle/Upper Berriasian boundary (Blau & Grün 1997), even though there is no final agreement on the substage division of the Berriasian. Later on, *Calpionellopsis oblonga* and *Nannoconus steinmannii steinmannii* make their first co-occurrences (at the base of the Calpionellopsis oblonga Subzone). In the upper portion of this subzone there is a coincidence of the FOs of calpionellid *Remaniella filipescui* and the dinocyst *Stomiosphaera wanneri*, the latter event defining the base of the St. wanneri dinocyst zone (Fig. 9).

The Berriasian/Valanginian boundary remains hardly determinable in terms of microfossil bioevents and zonations because the only criterion to place this boundary is the FO of *Praecalpionellites murgeanui* (the lower boundary of Pr. murgeanui calpionellid subzone), a species which is very rare indeed. On the other hand, within the basal Valanginian it is much easier to recognize the lower boundary of the Calpionellites Zone (FO of *Calpionellites darderi*), coinciding with the lower boundary of the Colomisphaera conferta dinocyst zone defined by the FO of *C. conferta* (Fig. 9).

At the Lower/Upper Valanginian boundary or a little lower, the FOs of two dinocyst species, *Carpistomiosphaera valanginiana* and *Colomisphaera vogleri*, are used to define the base of the C. valanginiana Zone. The LO of representatives of the genus *Calpionellites* which approximates this event is much more difficult to recognize because the extinction is rather gradual and slow. In the Late Valanginian (lower part of Tintinnopsella Zone) the first co-occurrences of the nannofossil species *Diadorhombus rectus* and the calcareous dinocyst *Stomiosphaera echinata* are recorded (the base of the St. echinata Zone) (Figs. 4, 6). A Late Valanginian–Early Hauterivian age is suggested for this zone on the basis of diagnostic ammonite finds.

Apart from the coinciding events in the evolution of calpionellids, nannofossils and calcareous dinocysts reviewed above, there is a number of non-coinciding events which can be helpful for finer and more precise subdivision and correlation of the Tithonian, Berriasian and Valanginian stages (Fig. 9). Moreover, this triple common study of stratigraphic ranges, bioevents and zonations may serve as a reference biochronology of the Tithonian to Valanginian age and provides a background for further application of independent studies on nannofossils and/or dinocysts in different lithologies lacking calpionellids.

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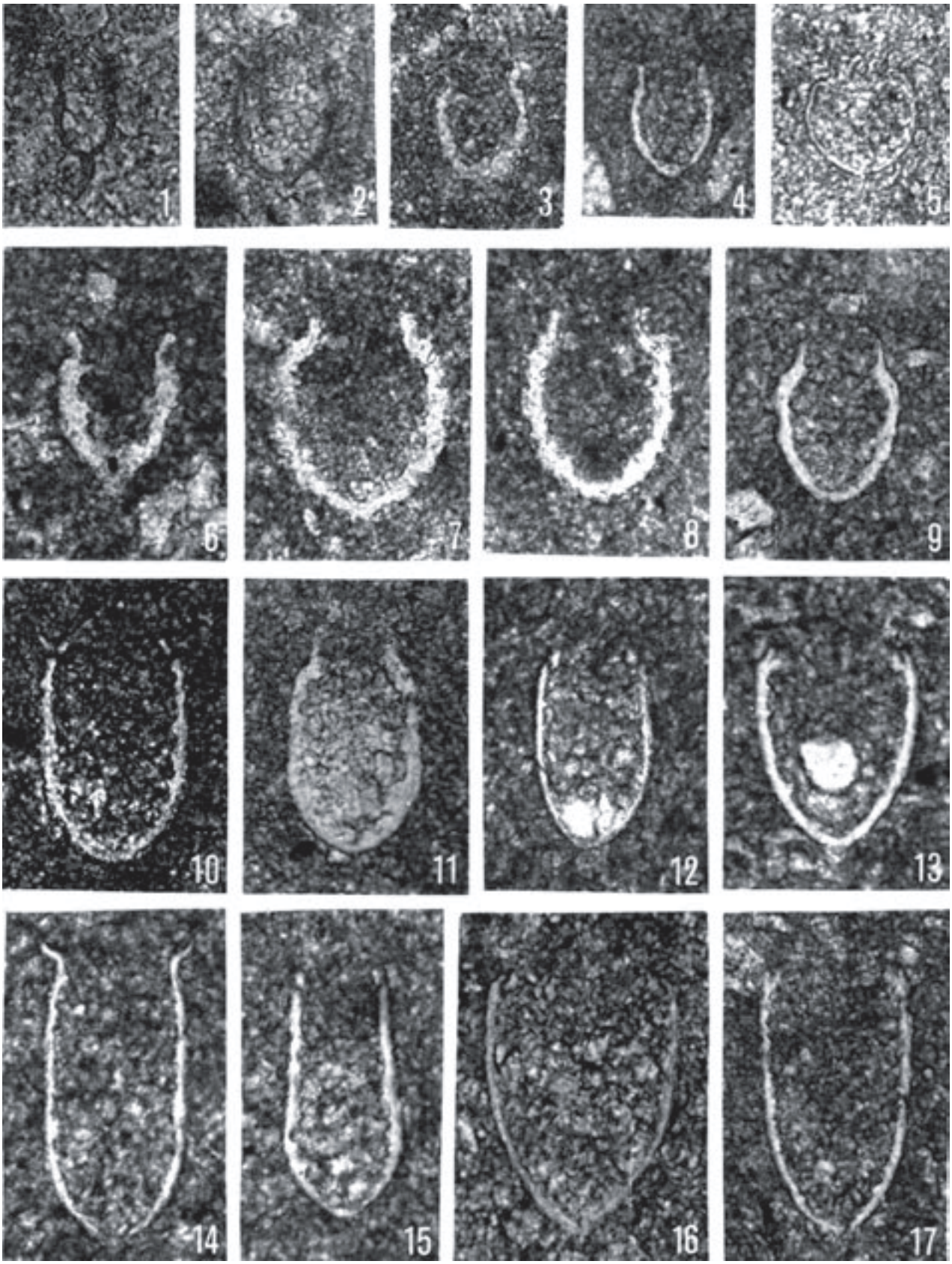
Plate I: Calpionellids of the Western Balkanides, Bulgaria. (All figures 500×). **Fig. 1.** *Chitinoidella dobeni* Borza, Middle Tithonian, Chitinoidella Zone, Ch. dobeni Subzone, Gorno Belotintsi 1 section, sample 15. **Fig. 2.** *Chitinoidella boneti* Doben, Middle Tithonian, Chitinoidella Zone, Ch. boneti Subzone, Barlya section, sample 0302. **Fig. 3.** *Tintinnopsella remanei* Borza, Upper Tithonian, Crassicollaria Zone, T. remanei Subzone, Barlya section, sample 301. **Fig. 4.** *Calpionella minuta* Houša, Middle Berriasian, Calpionella Zone, C. elliptica Subzone, Gorno Belotintsi 1 section, sample 48. **Fig. 5.** *Lorenziella hungarica* Knauer & Nagy, Lower Valanginian, Calpionellites Zone, Ctes major Subzone, Gorno Belotintsi 2 section, sample 70. **Fig. 6.** *Crassicollaria brevis* Remane, Upper Tithonian, Crassicollaria Zone, Cr. massutiniana Subzone, Gorno Belotintsi 1 section, sample 27. **Fig. 7.** *Calpionella grandalpina* Nagy, Upper Tithonian, Crassicollaria Zone, Cr. massutiniana Subzone, sample 28. **Fig. 8.** *Calpionella elliptalpina* Nagy, Upper Tithonian, Crassicollaria Zone, Cr. massutiniana Subzone, Gorno Belotintsi 1 section, sample 26. **Fig. 9.** *Calpionella alpina* Lorenz, Middle Berriasian, Calpionella Zone, C. elliptica Subzone, Gorno Belotintsi 1 section, sample 48. **Fig. 10.** *Remaniella ferasini* (Catalano), Middle Berriasian, Calpionella Zone, C. elliptica Subzone, Gorno Belotintsi 1 section, sample 51. **Fig. 11.** *Calpionella elliptica* Cadisch, Middle Berriasian, Calpionella Zone, C. elliptica Subzone, Gorno Belotintsi 1 section, sample 51. **Fig. 12.** *Calpionellopsis simplex* (Colom), Upper Berriasian, Calpionellopsis Zone, Csis simplex Subzone, Barlya section, sample 332. **Fig. 13.** *Calpionellites darderi* (Colom), Lower Valanginian, Calpionellites Zone, Ctes major Subzone, Gorno Belotintsi 2 section, sample 75. **Fig. 14.** *Tintinnopsella longa* (Colom), Upper Berriasian, Calpionellopsis Zone, Csis oblonga Subzone, Barlya section, sample 334. **Fig. 15.** *Calpionellopsis oblonga* (Cadisch), Upper Berriasian, Calpionellopsis Zone, Csis oblonga Subzone, Barlya section, sample 335. **Fig. 16.** *Fraecalpionellites murgeanui* (Pop), Lower Valanginian, Calpionellites Zone, Ctes darderi Subzone, Barlya section, sample 340. **Fig. 17.** *Calpionellites major* (Colom), Lower Valanginian, Calpionellites Zone, Ctes major Subzone, Gorno Belotintsi 2 section, sample 67.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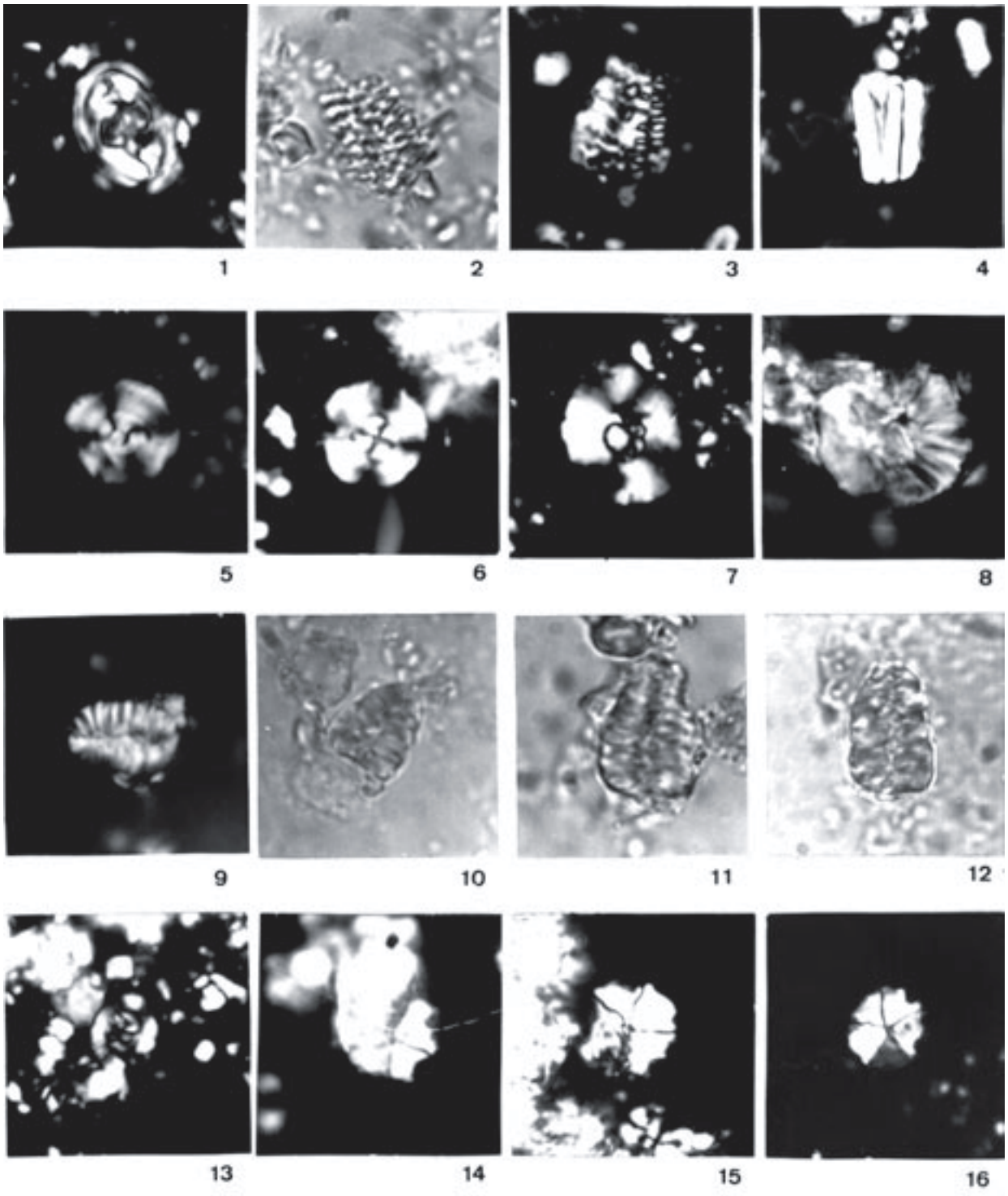

Plate II: Calcareous nannofossils from the Western Balkanides, Bulgaria. (All figures 2000×, except otherwise stated). **Fig. 1.** *Parhabdolithus embergeri* (Noël) Stradner, Upper Kimmeridgian, P. embergeri Zone, Barlya section, sample 59. **Figs. 2, 3.** *Faviconus multicolumnatus* Bralower, Lower Berriasian, M. chiastius Zone, Barlya section, sample 319. **Fig. 4.** *Conusphaera mexicana mexicana* Trejo, Lower Berriasian, M. chiastius Zone, Barlya section, sample 320. **Fig. 5.** *Cyclagelosphaera deflandrei* Manivit, Lower Valanginian, N. steinmannii Zone, sample 339. **Fig. 6**. *Cyclagelosphaera deflandrei* Manivit, Upper Valanginian, Gorno Belotintsi 2 section, sample 80. **Fig. 7**. *Cruciellipsis cuvillieri* (Manivit) Thierstein, Lower Valanginian, N. steinmannii Zone, Gorno Belotintsi 2 section, sample 67. **Fig. 8**. *Nannoconus globulus globulus* Brönnimann, Lower Valanginian, N. steinmannii Zone, Barlya section, sample 339. **Fig. 9**. *Nannoconus compressus* Bralower & Thierstein, Lower Berriasian, M. chiastius Zone, Barlya section, sample 310. **Fig. 10.** *Nannoconus steinmannii minor* Deres & Achéritéguy, Upper Berriasian, N. steinmannii Zone, Barlya section, sample 332. **Fig. 11**. *Nannoconus steinmannii steinmannii*

List of taxa recorded

Calpionellids

Chitinoidella dobeni Borza
Chitinoidella slovenica Borza
Chitinoidella colomi Borza
Chitinoidella tithonica Borza
Chitinoidella boneti Doben
Praetintinnopsella andrusovi Borza
Tintinnopsella carpathica (Murgeanu & Filipescu)
Tintinnopsella remanei Borza
Tintinnopsella longa (Colom)
Tintinnopsella subacuta (Colom)
Tintinnopsella dacica Filipescu & Dragastan
Crassicollaria intermedia (Durand Delga)
Crassicollaria massutiniana (Colom)
Crassicollaria brevis Remane
Crassicollaria parvula Remane
Crassicollaria colomi Doben
Calpionella alpina Lorenz
Calpionella grandalpina Nagy
Calpionella elliptalpina Nagy
Calpionella minuta Houša
Calpionella elliptica Cadisch
Remaniella ferasini (Catalano)
Remaniella duranddelgai Pop
Remaniella cadischiana (Colom)
Remaniella filipescui Pop
Calpionellopsis simplex (Colom)
Calpionellopsis oblonga (Colom)
Lorenziella hungarica Knauer & Nagy
Lorenziella plicata Remane
Sturiella oblonga Borza
Sturiella dolomitica Grün & Blau
Praecalpionellites murgeanui (Pop)
Praecalpionellites siriniaensis Pop
Calpionellites darderi (Colom)
Calpionellites coronata Trejo
Calpionellites uncinata Cita & Pasquaré
Calpionellites major (Colom)
Calpionellites caravacaensis Allemann

Calcareous nannofossils

Assipetra infracretacea (Thierstein) Roth
Calcicalathina oblongata (Worsley) Thierstein
Conusphaera mexicana mexicana Trejo
Conusphaera mexicana minor Bralower
Cretarhabdus angustiforatus (Black) Bukry
Cruciellipsis cuvillieri (Manivit) Thierstein
Cyclagelosphaera deflandrei Manivit
Diadorhombus rectus Worsley
Faviconus multicolumnatus Bralower
Micrantholithus hoschultzii (Reinhardt) Thierstein
Micrantholithus speetonensis Perch-Nielsen
Microstaurus chiastius (Worsley) Grün in Grün & Allemann
Nannoconus bermudezii Brönnimann
Nannoconus compressus Bralower & Thierstein
Nannoconus cornuta Deres & Achéritéguy
Nannoconus dolomiticus Cita & Pasquaré
Nannoconus globulus globulus Brönnimann
Nannoconus globulus minor Bralower
Nannoconus quadratus (Noël) Deres & Achéritéguy
Nannoconus steinmannii steinmannii Kamptner
Nannoconus steinmannii minor Deres & Achéritéguy
Farhabdolithus embergeri (Noël) Strander
Polycostella beckmannii Thierstein
Polycostella senaria Thierstein
Tubodiscus verenae Thierstein
Umbria granulosa granulosa Bralower & Thierstein

Calcareous dinocysts

Cadosina fusca fusca Wanner
Cadosina fusca cieszynica Nowak
Cadosina minuta Borza
Cadosina parvula Nagy
Cadosina semiradiata olzae Nowak
Cadosina semiradiata semiradiata Wanner
Carpistomiosphaera borzai (Nagy)
Carpistomiosphaera tithonica Nowak
Carpistomiosphaera valanginiana Borza
Colomisphaera carpathica (Borza)
Colomisphaera cieszynica Nowak
Colomisphaera conferta Řehánek
Colomisphaera fortis Řehánek
Colomisphaera heliosphaera (Vogler)
Colomisphaera lapidosa (Vogler)
Colomisphaera lucida Borza
Colomisphaera minutissima (Colom)
Colomisphaera nagyi (Borza)
Colomisphaera pieniniensis (Borza)
Colomisphaera tenuis (Nagy)
Colomisphaera vogleri (Borza)
Committosphaera pulla (Borza)
Committosphaera sublapidosa (Vogler)
Parastomiosphaera malmica (Borza)
Stomiosphaera alpina (Leischner)
Stomiosphaera echinata Nowak
Stomiosphaera moluccana Wanner
Stomiosphaera wanneri Borza
Stomiosphaerina proxima Řehánek

Continuation of the text to Plate II

Kamptner, Upper Berriasian, N. steinmannii Zone. **Fig. 12.** *Nannoconus steinmannii steinmannii* Kamptner, Upper Berriasian, N. steinmannii Zone, Gorno Belotintsi 1 section, sample 52. **Fig. 13**. *Microstaurus chiastius* (Worsley) Grün in Grün & Allemann, Upper Tithonian, M. chiastius Zone, Barlya section, sample 307, 1000×. **Fig. 14**. *Micrantholithus speetonensis* Perch-Nielsen, Upper Berriasian, N. steinmannii Zone, Barlya section, sample 335, 1000×. **Fig. 15**. *Micrantholithus speetonensis* Perch-Nielsen, Upper Valanginian, T. verenae Zone, Barlya section, sample 107, 1000×. **Fig. 16.** *Micrantholithus speetonensis* Perch-Nielsen, Upper Berriasian, N. steinmannii Zone, Gorno Belotintsi 1 section, sample 53, 1000×.

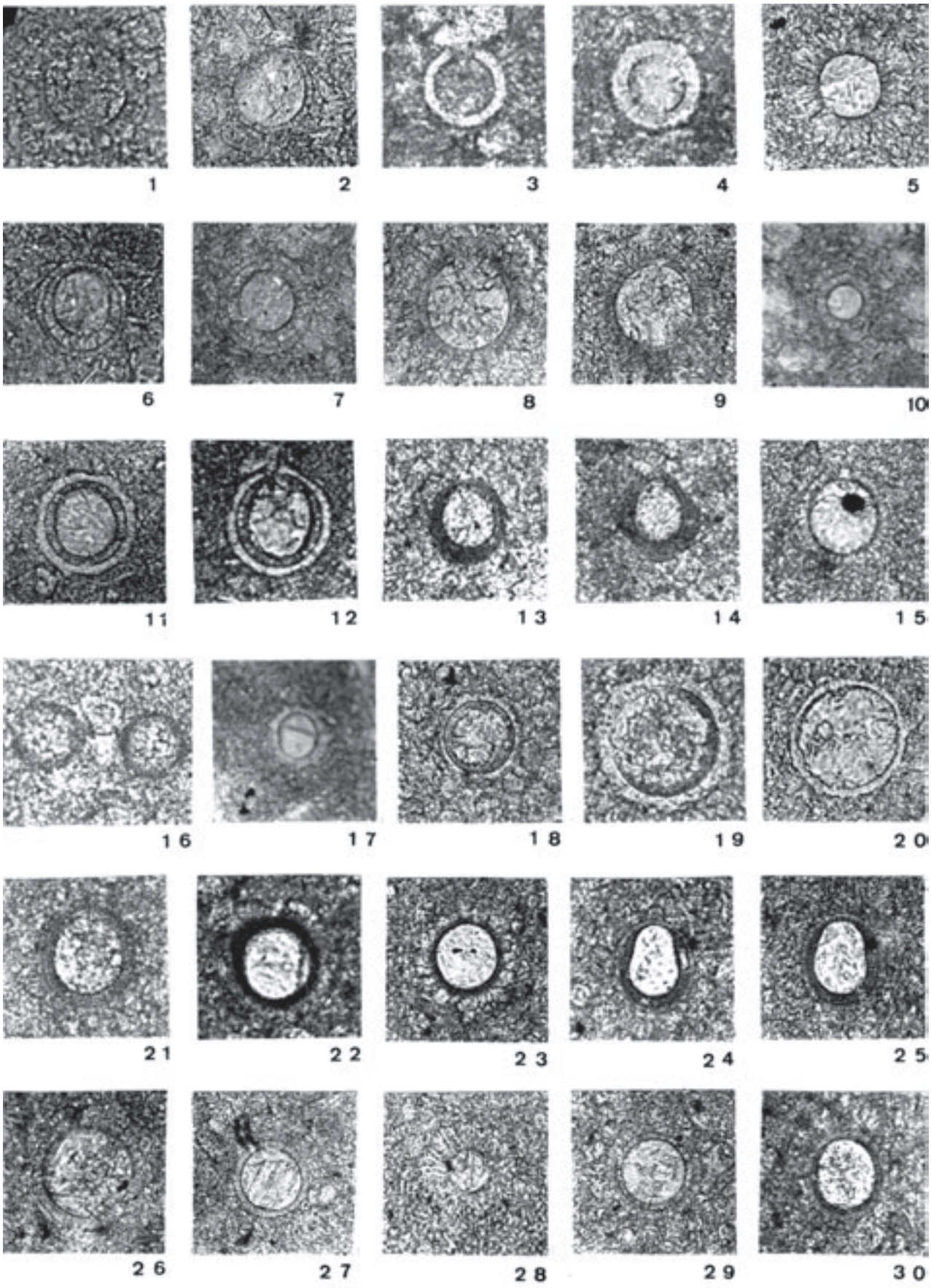
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Plate III: Calcareous dinocysts from the Western Balkanides, Bulgaria. (All figures 400×, except otherwise stated). **Fig. 1.** *Colomisphaera nagyi* Borza, Upper Kimmeridgian, C. borzai Zone, Gorno Belotintsi 1 section, sample 5. **Fig. 2.** *Colomisphaera pieniniensis* (Borza), Upper Kimmeridgian, C. borzai Zone, Gorno Belotintsi 1 section, sample 8. **Figs. 3, 4.** *Stomiosphaera moluccana* Wanner, Upper Kimmeridgian, C. borzai Zone, Gorno Belotintsi 1 section, samples 3, 10. **Fig. 5.** *Colomisphaera carpathica* (Borza), Lower Tithonian, C. tithonica Zone, Gorno Belotintsi 1 section, sample 11. **Figs. 6, 7.** *Carpistomiosphaera borzai* Borza, Lower Tithonian, C. borzai Zone, Gorno Belotintsi 1 section, samples 5, 9. **Figs. 8, 9.** *Carpistomiosphaera tithonica* Nowak; 8 — Lower Tithonian, C. tithonica Zone, Gorno Belotintsi 1 section, sample 10; 9 — Middle Tithonian, C. tenuis Zone, Gorno Belotintsi 1 section, sample 16. **Fig. 10.** *Colomisphaera tenuis* (Nagy), Middle Tithonian, C. tenuis Zone, Gorno Belotintsi 1 section, sample 17. **Figs. 11, 12.** *Parastomiosphaera malmica* (Borza), Lower Tithonian, P. malmica Zone, Gorno Belotintsi 1 section, samples 12, 14. **Figs. 13, 14.** *Cadosina fusca fusca* Wanner; 13 — Middle Tithonian, C. tenuis Zone, Gorno Belotintsi 1 section, sample 18; 14 — Lower Berriasian, St. proxima Zone, Gorno Belotintsi 1 section, sample 38. **Fig. 15.** *Colomisphaera fortis* Řehánek, Upper Tithonian, C. fortis Zone, Gorno Belotintsi 1 section, sample 23. **Fig. 16.** *Cadosina minuta* Borza, Upper Berriasian, St. wanneri Zone, Gorno Belotintsi 1 section, sample 54. **Fig. 17.** *Stomiosphaera wanneri* Borza, Upper Berriasian, St. wanneri Zone, Gorno Belotintsi 1 section, sample 53. **Figs. 18, 19.** *Stomiosphaerina proxima* Řehánek; 18 — Upper Berriasian, St. proxima Zone, Gorno Belotintsi 1 section, sample 52; 19 — Lower Berriasian, St. proxima Zone, Gorno Belotintsi 1 section, sample 42. **Fig. 20.** *Stomiosphaera alpina* Leischner, Middle Berriasian, St. proxima Zone, Gorno Belotintsi 1 section, sample 49. **Fig. 21.** *Colomisphaera vogleri* (Borza), Lower Valanginian, C. valanginiana Zone, Gorno Belotintsi 2 section, sample 75. **Figs. 22, 23.** *Cadosina semiradiata semiradiata* Wanner; 22 — Lower Tithonian, C. tithonica Zone, Gorno Belotintsi 1 section, sample 10; 23 — Lower Valanginian, C. conferta Zone, Gorno Belotintsi 2 section, sample 65, 300×. **Figs. 24, 25.** *Cadosina semiradiata olzae* Nowak, Lower Valanginian, C. conferta Zone, Gorno Belotintsi 2 section, samples 65, 69, 300×. **Figs. 26, 27.** *Colomisphaera conferta* Řehánek; 26 — Lower Valanginian, C. conferta Zone, Gorno Belotintsi 1 section, sample Sal 1; 27 — Lower Valanginian, C. conferta Zone, Gorno Belotintsi 2 section, sample 61, 300×. **Fig. 28.** *Colomisphaera heliosphaera* (Vogler), Lower Valanginian, C. conferta Zone, Gorno Belotintsi 2 section, sample 58, 300×. **Figs. 29, 30.** *Carpistomiosphaera valanginiana* Borza; 29 — Lower Valanginian, C. valanginiana Zone, Gorno Belotintsi 2 section, sample 73, 300×; 30 — Upper Valanginian, C. valanginiana Zone, Gorno Belotintsi 2 section, sample 84, 300×.

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