

## ACRITARCHS FROM THE CAMBRIAN—ORDOVICIAN BOUNDARY BEDS AT TÖNISMÄGI, TALLINN, NORTH ESTONIA

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**Abstract.** The general distribution of palynomorphs through the Cambrian—Ordovician boundary interval at Tönismägi allows to establish five acritarch assemblages corresponding to the *P. spinolosa*, *Cordylodus proavus*, *C. intermedius*, *C. lindstromi*, and *C. angulatus*—*C. rotundatus* zones. Two new species are described (?*Cymatiogalea procuillieri* sp. n. and *Stelliferidium cortinulamorphum* sp. n.).

**Key words:** acritarch, biostratigraphy, Upper Cambrian, Tremadoc, Estonia.

### INTRODUCTION

Several faunal groups have been studied from the Tönismägi outcrop to define the Cambrian—Ordovician boundary in the Baltic region (Kaljo et al., 1988). Unfortunately, the Upper Cambrian and Tremadoc sequence, characterized by shallow water terrigenous rocks in the Baltic—Ladoga klint area and an incomplete discontinuous succession with numerous disconformities, does not suit as key section for a boundary. Previous information on the lithology, sedimentology, and fossil records from Tönismägi is given in Kaljo et al. (1988). The present paper adds some more information on the distribution of the acritarchs in the same section. The 19 samples studied were collected from two profiles located about 50 m from each other (see Fig. 1). Most of them, excluding those from the Tiskre Formation (Lower Cambrian), contain acritarchs, of medium to good preservation.

Three different levels (*Cordylodus proavus*, *C. intermedius*, or *C. lindstromi*) have been proposed to be discussed by the International Working Group on the Cambrian—Ordovician Boundary. However, no final decision has been made yet. For this reason the lower boundary of the Tremadoc remains open in this paper.

### DISTRIBUTION OF ACRITARCHS

The acritarchs identified from the Tönismägi-section are listed in Fig. 2. Some selected acritarchs are illustrated on Pls. I—III. Their general distribution through the study interval allows of the establishment of five acritarch assemblages, which are numbered formally as A1—A5.

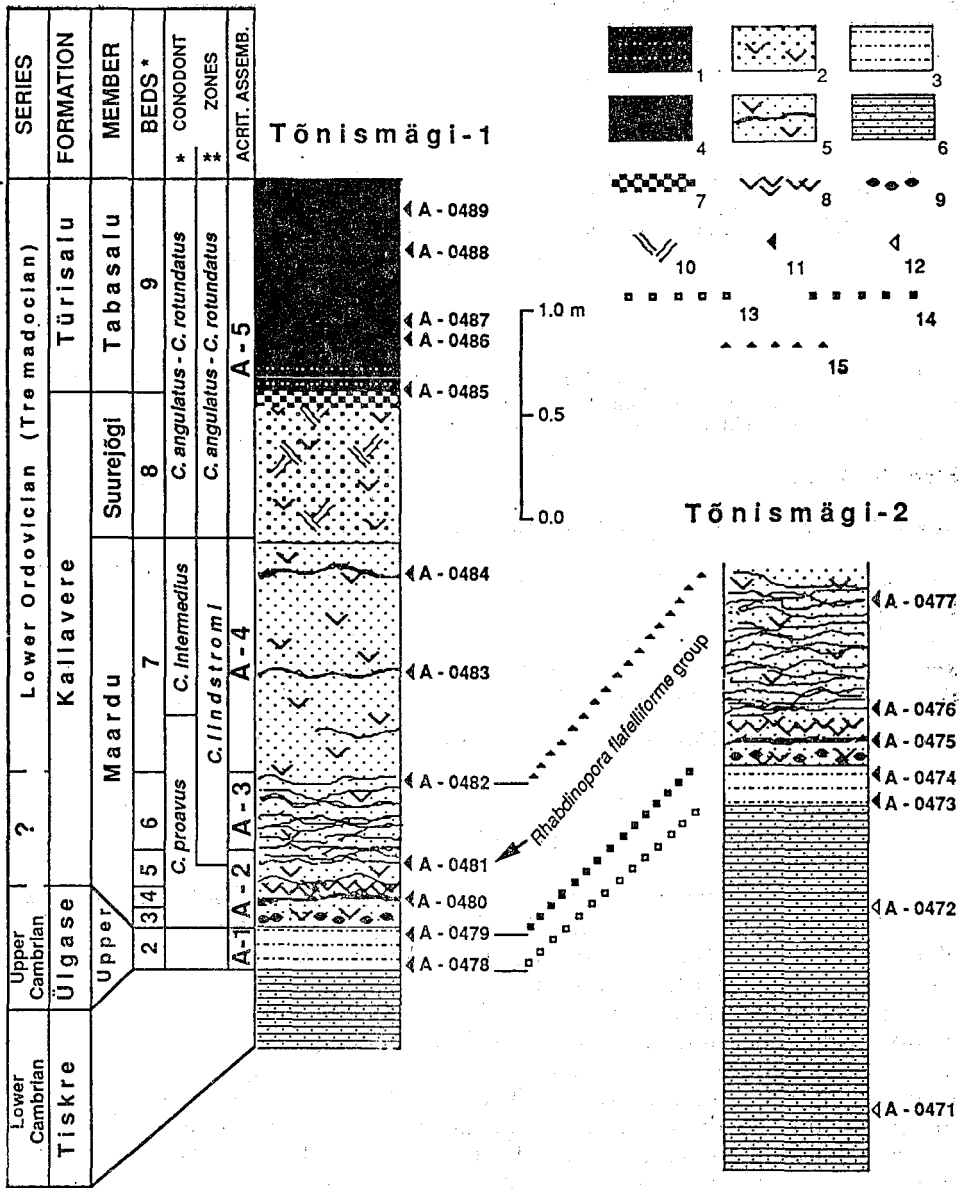


Fig. 1. The geological succession through the Cambrian—Ordovician boundary interval at Tõnismägi.

1 thin laminated organic-rich argillites; 2 coarse-grain sandstone with detritus; 3 silt-stone; 4 compact organic-rich argillites; 5 sandstone with interbeds of organic-rich argillites and detritus; 6 intercalation of silt- and claystones; 7 pyrite-rich horizon; 8 "obolus-coquina"; 9 basal conglomerate; 10 cross-bedding; 11 sample with acritarchs; 12 sample without acritarchs; 13 the upper boundary of the Tiskre Formation; 14 the upper boundary of the Ülgase Formation; 15 the approximate lower boundary of Bed 7; \* subdivision by Kaljo et al., 1988; \*\* subdivision by Norford, 1991.

Fig. 2. The distribution of the acritarchs through the Cambrian—Ordovician boundary interval in the Tõnismägi section.



PLATE I

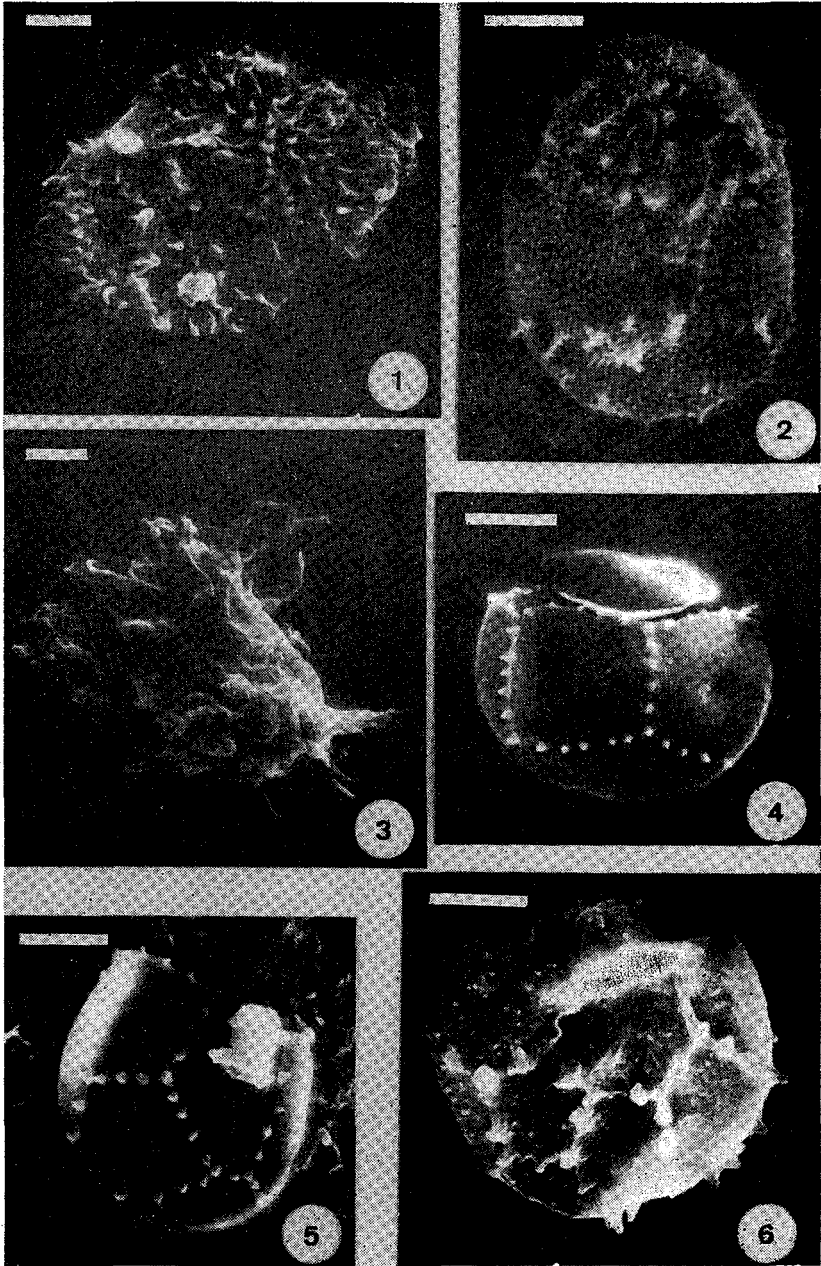


Fig. 1. *Acanthodiacrodium angustum* (Downie) Combaz; A-0477. Fig. 2. *Acanthodiacrodium comptulum* Rasul; A-0483. Fig. 3. *Arbusculidium destombesii* Deunff; A-0480. Figs. 4, 5. *Cymatiogalea cuvillieri* (Deunff) Deunff; A-0477. Fig. 6. *Cymatiogalea procuvillieri* sp. n. (holotype); A-0478.

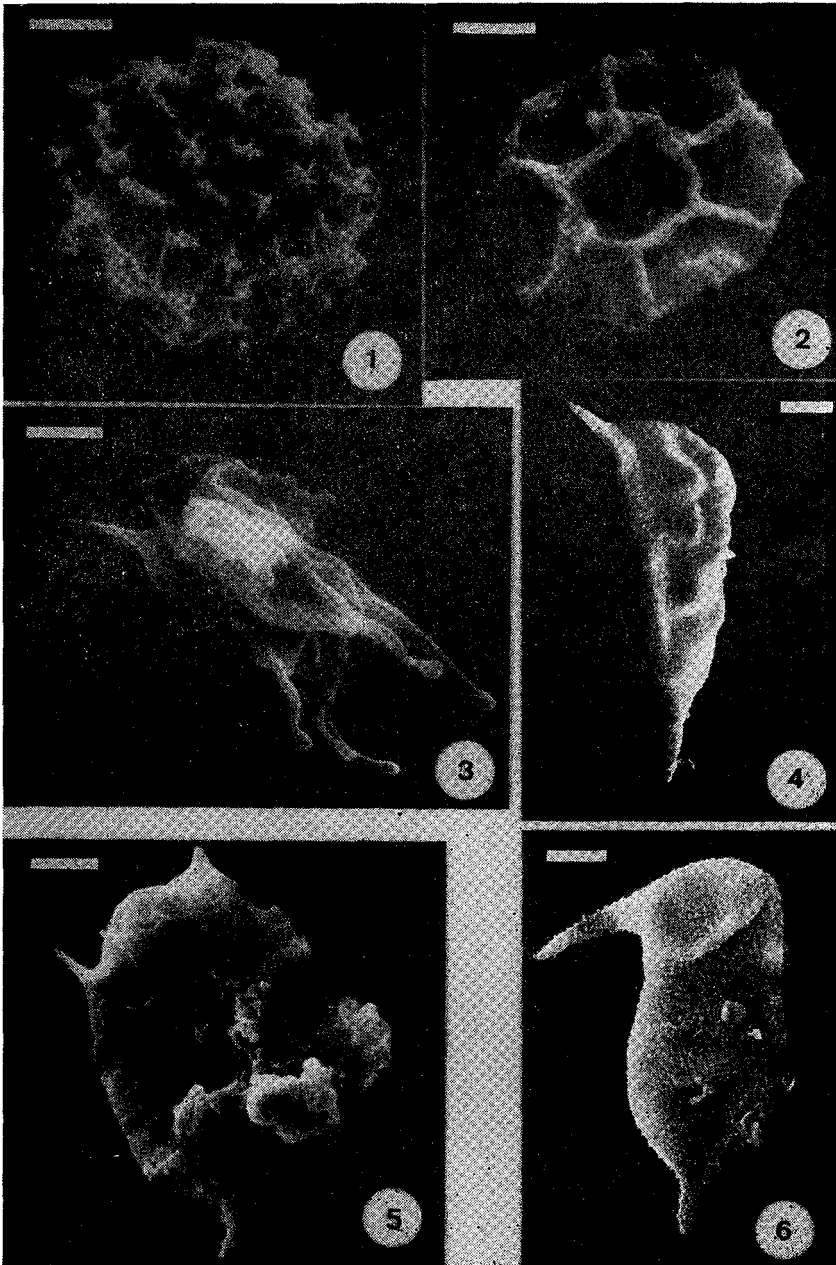


Fig. 1. *Vulcanisphaera imparilis* forma 4 Rasul; A-0485. Fig. 2. *Cymatiosphaera* sp.; A-0485. Fig. 3. *Priscotheca notata* Volkova; A-0483. Figs. 4, 6. ?*Leiofusa* sp.; Valkla, Ülgase Fm., sample A-0343. Fig. 5. *Priscotheca complanata* Deunff; A-0481.

PLATE III

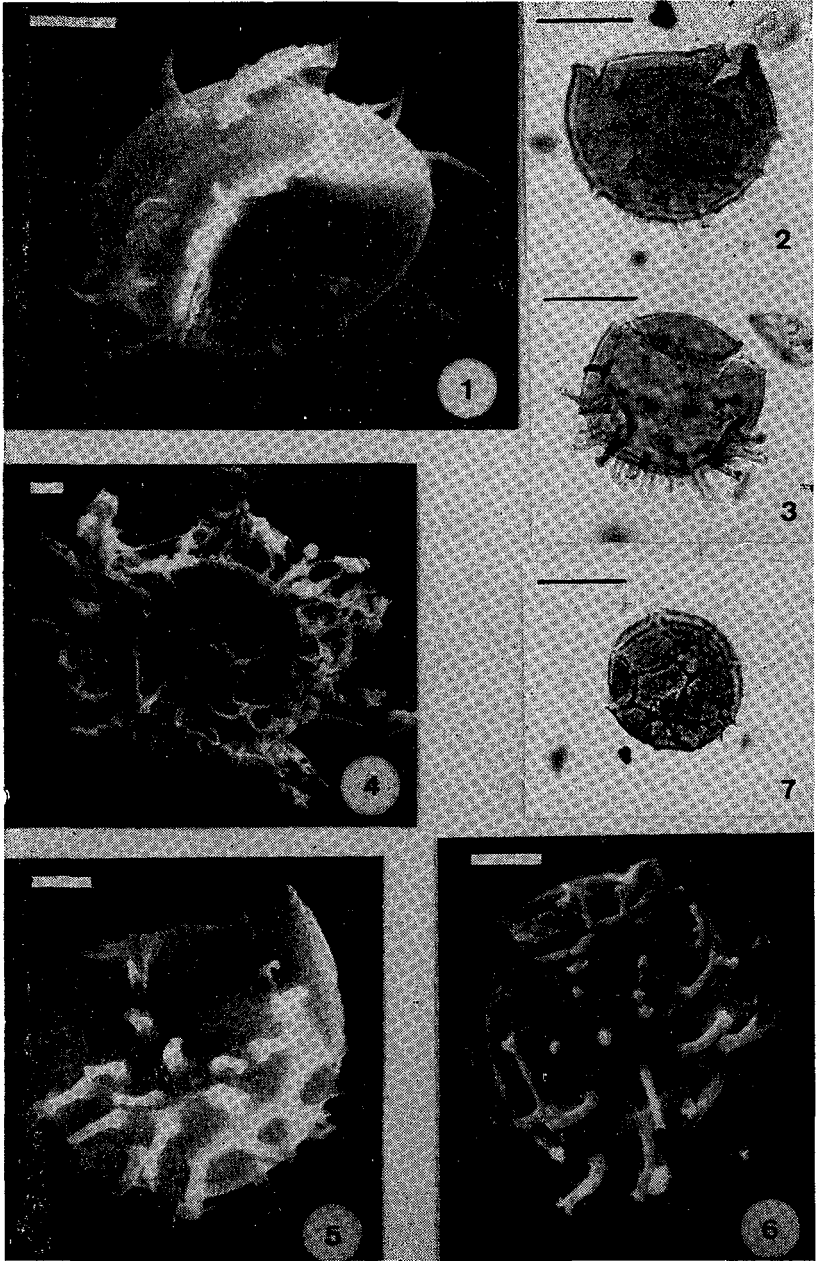


Fig. 1. ?*Baltisphaeridium* aff. "spinosum" Rasul; A-0483. Figs. 2, 3, 5. *Stelliferidium cortinulamorphum* sp. n. (holotype); A-0478. Fig. 4. *Trichosphaeridium hirtum* Timofeev; A-0481. Fig. 6. *Stelliferidium cortinulum* (Deunff) Deunff et al.; A-0477. Fig. 7. *Cymatiogalea procuillieri* sp. n.; A-0478.

The oldest microflora (A1), which contains typical Upper Cambrian acritarchs (Figs. 1, 2), comes from the Ülgase Formation at Tõnismägi (samples A-0473, A-0474, A-0478, A-0479). The same assemblage has been studied from different sections in North Estonia. At first it was considered to be an equivalent of the Tremadoc (Янкаускас & Пашкявичене, 1972; Аристова, 1976), but later reinterpreted as a typical late Cambrian microflora (Mens et al., 1989; Mens et al., 1993; Волкова, 1982, 1990; Волкова & Менс, 1988). Unfortunately, the Ülgase Formation is characterized by few fossil groups, only phosphatic inarticulate brachiopods *Ungula inornata* (Mickwitz) and *Lingulella* sp. were observed in the Tõnismägi locality (Kaljo et al., 1988). The former is considered to be a type species of *Ungula inornata*/*Angulotreta postapicalis* brachiopod Zone in the Baltic—Ladoga klint area (Puura & Holmer, 1993; Попов et al., 1989) corresponding to the lowermost part of the Upper Cambrian (approximately *A. pisiformis*—*P. spinulosa* trilobite zones). On the basis of previous acritarch records, the Ülgase Formation was correlated roughly with *Olenus* and *P. spinulosa* zones (Mens et al., 1989; Волкова, 1982). However, this silty lithounit seems to have deposited for a relatively short time limited with the *P. spinulosa* Zone. I would like to draw attention to some other arguments confirming this conclusion.

First, assemblage A-1 contains a peculiar acritarch determined here as ?*Leiofusa* sp. (Pl. II, figs. 4, 6). The same species was first described and illustrated by Potter (unpublished Ph. D. Thesis, 1974) as short-ranging *Leiofusa scalenabullata* sp. n. from the *P. spinulosa* Zone in Wales. In addition to Britain, a similar species is also found in Newfoundland where it is related to the lower and middle parts of the *P. spinulosa* Zone (Dr. Parsons, pers. comm.). The short-ranging ?*Leiofusa* sp. should be a good index acritarch for determining the *P. spinulosa* Zone in the East-European Platform as well as Britain and Newfoundland.

Secondly, the Upper Cambrian succession in Scandinavia indicates that the upper part of the *Olenus* Zone is usually missing except in Scania. The new transgression corresponding to the *P. spinulosa* Zone is registered elsewhere in Scandinavia, even in the Oslo region (see Martinsson, 1974, fig. 5). It is unlikely that the Baltic—Ladoga klint area, where the Upper Cambrian sequence is represented by terrigenous rocks typical of the shallow water conditions, was an area of sedimentation during the *Olenus* time, whereas at the same time a break is documented everywhere in Scandinavia. Probably, the Ülgase Formation was formed during the transgression recorded elsewhere in Scandinavia (Martinsson, 1974) and corresponds to the *P. spinulosa* Zone.

The lowermost part of the Maardu Member (= Beds 3—5) has been a subject of discussions for a couple of years. Bed 5 was previously correlated with the *C. proavus* Zone (Kaljo et al., 1988), but later reinterpreted by Norford (1991) and correlated with the base of the *C. lindstromi* Zone. Two samples, A-0480 and A-0475 collected from the argillite layer between the basal conglomerate and "obolus-coquina" (Fig. 1), contained *Acanthodiacrodium angustum* (Downie) Combaz, *A. sinuosum* Rasul, *Acanthodiacrodium* sp. 1, *Acanthodiacrodium* sp. 2, *Arbusculidium destombesii* Deunff, ?*Baltisphaeridium capillatum* Jardine et al., *Cristallinium* sp., *Cymatiogalea cuvillieri* (Deunff) Deunff, *Cymatiogalea* aff. *columellifera* (Deunff) Deunff, *Cymatiogalea* aff. *cristata* (Downie) Rauscher, *Micrhystridium* sp., *Priscotheca complanata* Deunff, *Stelliferidium cortinulum* (Deunff) Deunff, Gorka & Rauscher, *Stelliferidium* sp., *Trichosphaeridium hirtum* Timofeev, *Vulcanisphaera* sp. Two samples (A-0481 and A-0476), collected some centimetres above the "obolus-coquina" bed (= Bed 5), yielded all the above-listed species (except *Cristallinium* sp. and *Vulcanisphaera* sp.), additionally also *Acanthodiacrodium comptulum*

Rasul, *Arbusculidium striatulum* Volkova, and *Impluviculus* aff. *stellus* Rasul. The occurrence of graptolites from the *Rhabdinopora flabelliformis* group and of an element of *Iapetognathus preaengensis* on the same level (= Bed 5) adds confusion into the interpretation of this acritarch assemblage. The reason is that the first appearance of *Rhabdinopora*-type graptolites is regarded as a significant bioevent defining the lower boundary of the Tremadoc. This event was nearly contemporaneous with the appearance of *C. lindstromi*. This concept has found proof in several successions (Erdtmann, 1988; Fortey et al., 1991; Landing, 1993) and the earliest occurrence of *Rhabdinopora*-type graptolites in Estonia is considered to be questionable (Norford, 1991). One thing seems to be clear: A-2 from the base of the Maardu Member is older than A-4 distinguished from the upper part of the same unit (Figs. 1, 2). The general distribution of acritarchs within the Maardu Member indicates one or two discontinuities inside Bed 6 or at the base of Bed 7 at Tõnismägi.

A-2 contains several taxa, like *A. angustum*, *A. comptulum*, *A. destombesii*, and *A. striatulum*, which should be important from the biostratigraphic point of view. Up to now the last species has been recorded only in Estonia (Волкова, 1988) and it is probably endemic. *A. angustum* was proposed by Volkova (Волкова, 1990) to define the base of the Tremadoc (*sensu C. proavus*). This proposal was later discussed and criticized by Martin (1993). However, the results of several outcrop studies in Estonia (Волкова, 1989; Волкова & Менс, 1988) confirm that the earliest specimens of *A. angustum* are established within the *C. proavus* Zone and its appearance may have been coeval with that of the index conodont or even earlier.

Probably, the earliest *A. destombesii* was recorded by Welsch (1986) from the lower part of the Berlogaissa Formation, which shows a typical acritarch community of the *Peltura/Acerocare* zones, and by Volkova (Волкова, 1990) from the same level in the Baltic area and in the Moscow Basin. In eastern Newfoundland the first *A. destombesii* were documented from the bottom of the Clarendville Formation (Martin & Dean, 1981). This level is considered to be a critical one and correspond to the *Acerocare* Zone. The same species occurs, for instance in Morocco, in the base (= acritarch zone 1) of the Fezouata Formation (Elaouad-Debbaj, 1988). This portion of the formation (NBI with some graptolites determined as *Dictyonema* sp.) has been interpreted as the equivalent of the *Dictyonema flabelliforme* and Transitional Beds in Britain. The distribution of acritarchs through the Fezouata Formation indicates that the earliest acritarch assemblage comparable with acritarchs of the *Dictyonema flabelliforme* Beds in Britain (Rasul, 1979; Downie, 1984) could be assemblages 3 or 4 *sensu* Elaouad-Debbaj (1988) and in this case the lowermost part of the formation is older than considered earlier.

Unfortunately, not many successions proceeding through the Cambrian—Ordovician boundary interval have been studied in detail on acritarchs and other fossils. An exception is the Digermul section in the northern part of the East-European Platform where the first graptolites are documented in the lower part of the Berlogaissa Formation within acritarch biozone A-5 (Welsch, 1986). The Tremadoc age of assemblage A-5 was opposed and criticized by Volkova (Волкова, 1993). Its comparison with the material from the other parts of the East-European Platform shows quite clearly the late Cambrian age. With regard to the zonation proposed by Volkova (Волкова, 1990), the lowermost part of the Berlogaissa Formation (at least profile 1a—d in Digermul) is correlative with *Peltura* and/or *Acerocare* zones. However, the first *Rhabdinopora* are documented in the middle part of Be-1 (profile 2a—c) above the acritarch-bearing beds, whereas inside Be-1 at least two levels with ripple



marks (Welsch, 1986) are recorded. These may be indicative of discontinuities. The middle (Be-2) and upper (Be-3) parts of the Berlogaissa Formation are characterized by a relatively low diversity of the acritarch assemblage without any good index taxa. *C. cristata*, chosen by Welsch to define assemblage A-6, has similar forms already in the upper Cambrian rocks and its biostratigraphic value is rather questionable. Consequently, A-6 from the Berlogaissa Formation seems to be older than considered by Welsch (1986).

A-3 is established about 0.6 m above the base of the Maardu Member (= Bed 6). This part of the section, which is barren of conodonts, yields acritarchs represented in A-2 and some new taxa (*Acanthodiacrodium papillare* Timofeev, *Leiosphaeridia tenuissima* Eisenack, and *Lunulidia* sp.). Over 90% of acritarchs derived from samples A-0482 and A-0477 belong to *L. tenuissima* and *Leiosphaeridia* sp. The bloom of the leiosphaeriids is well known and typical for instance of the Türisalu Formation. However, the acanthomorphic and galeat acritarchs accompanying *L. tenuissima* in A-3 are quite distinctive from those in the Türisalu Formation (Fig. 2). The precise correlation of Bed 6 remains open because assemblage A-3 has an "intermediate face" between assemblages A-2 and A-4. Its correlation with the *C. intermedius* Zone is not excluded.

A-4 comes from the upper part of the Maardu Member and is characterized by several new species (Fig. 2). Kaljo et al. (1988) concluded that Bed 7 corresponds to the *C. intermedius* Zone. Norford (1991) and Landing (1993) reinterpreted previous fossil evidences and assigned this part of the section to the *C. lindstromi* Zone.

Several acritarch species represented in A-4 should be good index taxa for the determination of the *C. lindstromi* Zone and maybe also the Tremadoc boundary. *Baltisphaeridium* aff. "*spinosum*" Rasul, *Dasydiacrodium ornatum* Combaz, *Cymatiosphaera* sp. 1, and *Priscotheca notata* Volkova, observed in the Tönismägi section, have good correlation with *C. lindstromi*. Also some other taxa not represented at Tönismägi but documented in other localities (Orasoja and Lamoshka sections, unpublished data of I. Paalits) co-occur with *C. lindstromi*. These are *Acanthodiacrodium ubuii* Martin and the *Vulcanisphaera britannica* Rasul—*V. imparalis* Rasul group. In Shropshire (England) several above-mentioned species are first recorded in the *Dictyonema flabelliforme* Beds corresponding to the *C. lindstromi* Zone (Rasul, 1979). The assemblage A-4 has the best correlation and is comparable with acritarchs determined from the *Dictyonema flabelliforme* and Transitional Beds in Britain (Rasul, 1979; Downie, 1984) and with the Fezouata Formation (= acritarch zones 3 and 4) in Marocco (Elaouad-Debbaj, 1988).

The organic-rich argillites of the Türisalu Formation (Bed 9) corresponding to the *C. angulatus*—*C. rotundatus* Zone (Kaljo et al., 1988) contain low-diversity microflora (A-5) with the dominance of *L. tenuissima* and *Lophosphaeridium zaleskyi* (Naumova) Umnova accompanied by very rare acanthomorphic and galeat acritarchs (*Acanthodiacrodium* sp. 5, *Acanthodiacrodium* sp. 6, *Cymatiogalea cristata*, *Cymatiosphaera* sp. 2, *Leiosphaeridia voighti* Eisenack, *Stelliferidium pseudoornatum* Pittau, *S. distinctum* (Rasul), and *Vulcanisphaera imparilis* forma 4). A similar palynoflora appears to be typical of the deposits of the *C. angulatus* Zone in the East-European Platform (Eisenack, 1958; Tongiorgi & Ribecai, 1990; Умнова & Фандерфлит, 1971; Умнова, 1975).

## SYSTEMATIC DESCRIPTION

Abbreviations: Dv—diameter of vesicle; Lp—total length of process; Lfp—length of furcated part of process; Bp—basal breadth of process; Dpf—diameter of polygonal field; Dop—diameter of operculum; Np—number of processes.

### ALGAE INCERTAE SEDIS

Group ACRITARCHA Evitt, 1963

Genus *Cymatiogalea* Deunff, 1961, emend. Deunff, 1964, emend. Deunff, Gorka et Rauscher, 1974

?*Cymatiogalea procuwillieri* sp. n.

Pl. I, fig. 6, pl. III, fig. 7

1990 *Cymatiogalea* aff. *C. cuwillieri* (Deunff) Deunff, Gorka et Rauscher: Волкова, pl. 8, fig. 5.

1992 *Cymatiogalea* sp. 1: Paalits, Pl. I, fig. 3.

**Holotype:** Pl. I, fig. 6.

**Stratum typicum:** Ülgase Formation, Upper Cambrian.

**Locus typicus:** Tõnismägi section in Tallinn, North Estonia.

**Material:** more than 20 specimens.

**Diagnosis:** Vesicle originally globular. The processes are homomorphic and placed regularly dividing the vesicle into polygonal fields. The processes are small, solid, nonfurcated with acuminate or blunted tips. These have a curved contact with the vesicle and are proximally sometimes ornamented with a ray-like structure. The processes can be connected with each other with a fold.

The configuration of the fields is usually pentagonal. The hexagonal and quadrangular types of fields are rare. The edge of the fields is bordered by three processes. The formula of the tabulation is 1:6:6:1, 1:5:6:1, or 1:5:2. The surface on the vesicle is smooth or rugulated.

The excystment is represented by a pylom-like structure formed by separation of the pseudotabulae.

**Dimensions:** (10 specimens) Dv: 16.5—28.0 (20.1)  $\mu\text{m}$ ; Lp: 1.5—3.0 (2.0)  $\mu\text{m}$ ; Dpf: 6.0—8.5 (7.5)  $\mu\text{m}$ ; Dop: 8.0—11.5 (9.5)  $\mu\text{m}$ .

**Comparison:** ?*C. procuwillieri* sp. n. differs from *C. cuwillieri* (Pl. I, figs. 4, 5) in the number of the processes bordering the edge of the polygonal fields and in the morphology of processes. The holotype of *C. cuwillieri* illustrated by Deunff (1961) has four processes on an edge and it bears a well-developed typical macropylom, which is absent in ?*C. procuwillieri* sp. n.

**Remarks:** ?*C. procuwillieri* sp. n. has an excystment mode nontypical but quite commonly represented in several late Cambrian acritarchs, for instance *Raphesphaera* and *Cristallinium*. It is characterized by an unclearly developed pylom-like structure without a distinct operculum. The rupture-like opening of ?*C. procuwillieri* sp. n. follows the edges of the pseudotabulae (Pl. I, fig. 6). In the extreme case the opening rupture can occupy more than one pseudotabula (see also Волкова, 1990, pl. 8, fig. 5). It is supposed here that acritarchs of ?*C. procuwillieri* sp. n. type represent an ancestor lineage of the galeate acritarchs with an archaic excystment mode.

**Occurrence:** Ülgase and Tsitre formations, corresponding to the *Parabolina spinulosa* and *Leptoplastus* zones, Upper Cambrian, North Estonia (Paalits, 1992; Волкова, 1990).

Genus *Stelliferidium* Deunff, Gorka et Rauscher, 1974

*Stelliferidium cortinulamorphum* sp. n.

Pl. III, figs. 2, 3, and 5

1990 *Stelliferidium* aff. *S. cortinulum* (Deunff) Deunff, Gorka et Rauscher: Волкова, pl. 2, figs. 17 and 19.

1991 ?*Stelliferidium* sp. cf. *S. cortinulum* (Deunff) Deunff, Gorka et Rauscher: Di Milia, pl. 2, fig. 12.

1992 *Stelliferidium* sp.: Paalits, Pl. I, fig. 7.

**Holotype:** Pl. III, fig. 5.

**Stratum typicum:** Ülgase Formation, Upper Cambrian.

**Locus typicus:** Tõnismägi section in Tallinn, Estonia.

**Material:** over 200 specimens.

**Diagnosis:** Vesicle originally globular, with macropylom and covered with processes. These are heteromorphic and located irregularly on the antapex and regularly on the apex. The interval between processes varies from 2 to 5  $\mu\text{m}$ . The distal parts of the processes are furcated to the first or second order. The proximal parts of the processes are widened, they have curved contact with vesicle and are weakly ornamented with ray-like folds. The interior of processes is solid or hollow (represented by single trabeculates) without free communication into the vesicle cavity. The antapex is totally covered with processes. On the apex some processes are located regularly in rows. Usually four or five rows are formed in a tabulation-like order. The row consists of two or three processes.

The surface on the vesicle and on the operculum is uniform, rugulated. The configuration of the pylom and operculum is rounded, subrounded, or subpolygonal. The pylom is simple without or with a collar and decorated with knob-like nonfurcated processes.

**Dimensions:** Dv: 25.0—37.5 (31.6)  $\mu\text{m}$ ; Dop: 5.0—22.0 (17.5)  $\mu\text{m}$ ; Lp: 3.5—8.5 (6.5)  $\mu\text{m}$ ; Bp: 1.7—2.5 (2.3)  $\mu\text{m}$ ; Lfp: 0.5—4.5 (1.6)  $\mu\text{m}$ ; Np: 19—58 (37).

**Comparison:** *S. cortinulum* appears to be one of the most often cited acritarch species from the Upper Cambrian—Tremadocian rocks elsewhere in the world. However, its diagnosis seems to be unclearly defined. Typical *S. cortinulamorphum* sp. n. differs from *S. cortinulum* in the location of the processes, which are arranged irregularly on the anapex and placed regularly on the apex.

*S. cortinulamorphum* sp. n. may be an intermediate form between stelliferiids and cymatiogaleas because of common elements in the morphology of both genera. For instance, the ray-like structure on the bases of processes and their irregular location on the anapex pole is characteristic of stelliferiids and weakly developed pseudotabulation on the apex is a typical morphological element of cymatiogaleas.

**Occurrence:** Very common in the Ülgase and Tsitre formations, Upper Cambrian, *P. spinulosa*—*Leptoplastus* zones, North Estonia; Solanas Sandstone Formation, Upper Cambrian, Central Sardinia, Italy (Di Milia, 1991).

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## AKRITARHID KAMBRIUMI JA ORDOVIITSIUMI PIIRIKIINTIDEST TÕNISMÄE PALJANDIST TALLINNAS

Ivo PAALITS

Tõnismäe paljandist on võimalik välja eraldada vähemalt viis akritarhi kompleksi, mis on korreleeritavad *P. spinolosa*, *C. proavus*'e, *C. intermedius*'e, *C. lindstromi* ja *C. angulatus*'e—*C. rotundatus*'e tsoonidega. Graptoliite sisaldava Maardu kihistiku basaalis (kihid 3—5) leidub akritarhe, mis on iseloomulikud *C. proavus*'e tsoonile. *C. lindstromi* tsoonile tüüpilised akritarhid on aga määratud Maardu kihistiku ülemisest osast (kiht 7). Süstemaatilises osas on kirjeldatud kaht uut liiki (?*Cymatogalea procuvillieri* sp. n. ja *Stelliferidium cortinulamorphum* sp. n.).

## АКРИТАРХИ ПОГРАНИЧНЫХ СЛОЕВ КЕМБРИЯ И ОРДОВИКА ИЗ РАЗРЕЗА ТЫНИСМЯГИ, ТАЛЛИНН

Иво ПААЛИТС

В сводном разрезе пограничного интервала кембрия и ордовика, представленного отложениями юлгасеской, каллавереской и тюрисалуской свит, установлены пять комплексов акритарх. Нижний из них происходит из юлгасеской свиты, два следующих — из нижней части маардуской пачки каллавереской свиты, соответствующей конодонтовой зоне *Cordylodus proavus*, четвертый — из отложений зоны *C. lindstromi* и пятый — из отложений зоны *C. angulatus*—*C. rotundatus*.

Даны описания двух новых видов — ?*Cymatiogalea procuillieri* sp. n. и *Stelliferidium cortinulamorphum* sp. n.