

# ACRITARCH BIOSTRATIGRAPHY OF THE LOWER-MIDDLE CAMBRIAN BOUNDARY IN THE IBERIAN CHAINS, PROVINCE OF SORIA, NORTHEASTERN SPAIN

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## ABSTRACT

The Lower and Middle Cambrian age acritarch assemblages are reported from a continuous succession of the siliciclastic-carbonate Ribota, Huérmeda and Daroca Formations in the Iberian Chains, northeastern Spain. One new genus and four new species are described, one of them in open nomenclature. The microfossil assemblages allow to recognize the Lower Cambrian *Heliosphaeridium dissimulare-Skiagia ciliosa* and *Volkovia dentifera-Liepaina plana* acritarch zones, and to discuss an informal lowermost Middle Cambrian acritarch zone. These zones correspond respectively to the *Holmia kjerulfi*, *Protolenus* and *Acadoparadoxides oelandicus* trilobite zones, identified in the Acado-Baltic faunal province. The first appearance of *Eliasum llaniscum*, *Celtiberium dedalinum* and *Retisphaeridium dichamerum*, which are age-diagnostic for the Middle Cambrian, in the upper Daroca Formation is interpreted to point the Lower-Middle Cambrian boundary. This stratigraphic level underlies the previously established trilobite-based boundary. The depositional environments and biostratigraphy of the concerned strata are discussed.

**Key words:** Acritarchs, biozonation, Lower Cambrian-Middle Cambrian, Iberian Chains, Northeastern Spain.

## RESUMEN

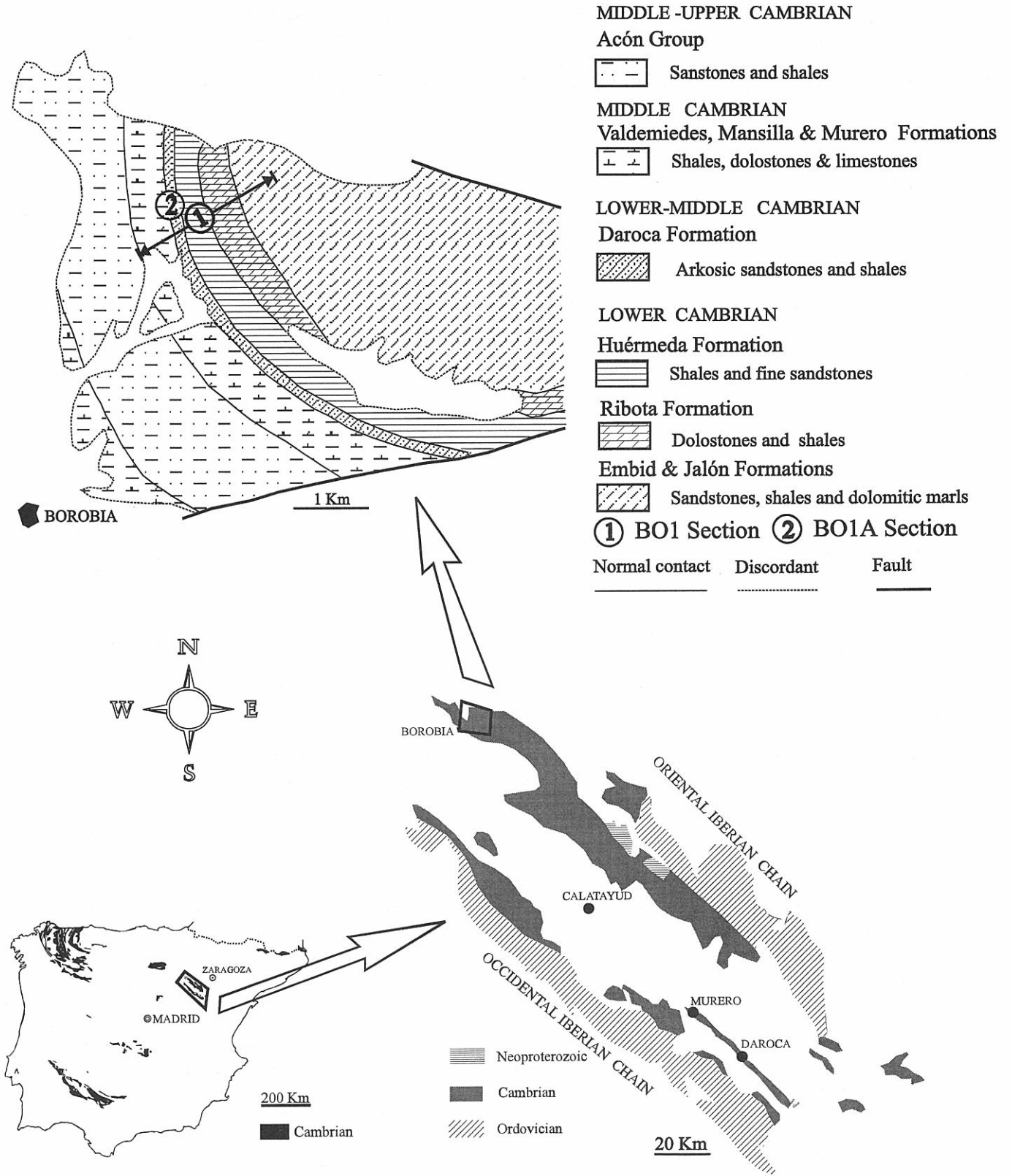
Se refieren varias asociaciones de acritarcos del Cámbrico Inferior y Cámbrico Medio en las Cadenas Ibéricas, España nororiental, a lo largo de una sucesión continua de materiales carbonatados y siliciclásticos de las formaciones Ribota, Huérmeda y Daroca. Se describe un género nuevo y cuatro especies, una de ellas en nomenclatura abierta. Las asociaciones de microfósiles permiten reconocer las biozonas de *Heliosphaeridium dissimulare-Skiagia ciliosa* y *Volkovia dentifera-Liepaina plana* del Cámbrico Inferior y una asociación, todavía no formalizada, del Cámbrico Medio. Las zonas del Cámbrico inferior se corresponden con las de trilobites de *Holmia kjerulfi*, *Protolenus* y la asociación del Cámbrico Medio con la zona de *Acadoparadoxides oelandicus*, identificadas en la provincia Acado-Báltica. Se propone como indicativo del límite Cámbrico Inferior-Cámbrico Medio la primera aparición en la parte superior de la Formación Daroca, de las especies *Eliasum llaniscum*, *Celtiberium dedalinum* y *Retisphaeridium dichamerum*, diagnósticas del Cámbrico Medio. Este nivel estratigráfico se sitúa por debajo el límite propuesto anteriormente mediante trilobites. Por último se discuten la biostratigrafía de los estratos que contienen las asociaciones de acritarcos y el ambiente de depósito, este último con base en el registro continuo de palinofacies.

**Palabras clave:** Acritarcos, biozonación, Cámbrico Inferior-Cámbrico Medio, Cadenas Ibéricas, Noreste de España.

## INTRODUCTION

The Lower and Middle Cambrian sedimentary rocks are widespread and well exposed in the Iberian Peninsula

(Fig. 1), and have been intensively studied for the fossil content and biostratigraphy. They represent detrital and carbonate successions that are unevenly tectonically deformed in different regions, being thermally altered up



to low grade of metamorphism. Despite of this, the sedimentary structures, spacial facies distribution and the fossils, both with hard skeletons and organic-walled, are

well preserved and serve as an excellent field for depositional, environmental and palaeobiological investigations.

The biostratigraphic subdivision of the Lower and Middle Cambrian in Iberia was formalized by Sdzuy (1968, 1971 a, b, 1972), Liñán (1984), Liñán, Perejón and Sdzuy (1993), and compiled by Liñán, Perejón *et al.* (1996) and Sdzuy *et al.* (1996). Among the other areas, the Iberian Chains are known for a wide extent of clastic shelf and carbonate platform deposits yielding faunas that have been used to define the Lower Cambrian regional stages.

Some organic-walled microfossils of planktonic, presumably algal and of other unknown protistan biological affinities referred to an informal group of Acritarcha Evitt, 1963, were abundantly recovered from the Cambrian strata in the Iberian Peninsula (Cramer and Díez Cramer, 1972; Fombella, 1977, 1978, 1979; Mette, 1989; Palacios and Vidal, 1992; Palacios, 1993; Vidal *et al.*, 1994). The acritarch-based biostratigraphy of the Cambrian (Martin and Dean, 1981, 1988; Vidal, 1981, 1985; Volkova *et al.*, 1983; Welsch, 1986; Di Milia *et al.*, 1989; Moczydłowska, 1991, in press; Vidal and Peel, 1993; Vidal and Moczydłowska, 1996; Zang, 1992), and in general of the lower Palaeozoic (see for a recent review Molyneux *et al.*, 1996) is in a great progress, being applied to successions in the palaeocontinents of Baltica, East Avalonia, Siberia, Laurentia and Gondwana. We report herein on the occurrence of acritarchs, including three new species, in the Borobia area, Province of Soria in the Iberian Chains, their taxonomy (with additional observations on material from the Zafra area in SW Spain), depositional environments and the biostratigraphy of the Lower-Middle Cambrian strata. The primary report on these acritarchs was earlier mentioned by Gámez *et al.* (1991). The stratigraphic level for the Lower-Middle Cambrian boundary is re-evaluated in the Iberian Chains and it is suggested to be placed within the Daroca Formation, in difference to the previously proposed position in the overlying Valdemiedes Formation.

## GEOLOGICAL SETTING

The Lower-Upper Cambrian siliciclastic-carbonate successions in the Iberian Chains overlie Neoproterozoic turbiditic strata with an angular unconformity which reflects the Cadomian phase of the Pan-African Orogeny (Vidal *et al.*, 1994). Neoproterozoic rocks, consisting of shale, sandstone, chert and oncolitic carbonate and referred to the Paracuellos Group are deformed and metamorphosed under low grade metamorphic conditions. They yielded an ichnofossil assemblage similar to that from the central part of Iberia and being indicative of the Vendian age (Liñán and Tejero, 1988). The Cambrian strata are transitionally overlain by Tremadocian shale and then the Armorican Quartzite (Liñán, Perejón *et al.*, 1996). They were affected by several tectonic episodes during the Variscan and Alpine orogenies resulting in chain folding and development of schistosity.

The Lower-Middle Cambrian successions exceed

2,300 m in thickness and comprise, in the ascending order, the Bámbola, Embid, Jalón, Ribota, Huérmeda, Daroca, Valdemiedes, Mansilla and Murero formations and Acón Group (Gozalo, 1995). Their biostratigraphy is established on the occurrence of trilobites (Lotze, 1961; Sdzuy, 1961; Sdzuy, 1971 a, b; for a recent review see Liñán, Perejón and Sdzuy, 1993 and Liñán, Perejón *et al.*, 1996), trace fossils (Valenzuela *et al.*, 1990), and more recently acritarchs (Gámez *et al.*, 1991; Liñán, Villas *et al.*, 1996; and present study). The Upper Cambrian detrital rocks, approaching in thickness almost 1,000 m (Liñán, Villas *et al.*, 1996), are out of scope of the present paper.

The basal portion of the Cambrian succession in the study area, consisting of alternating sandstone and shale with intercalations of carbonates of the Jalón Formation form a sequence of prograding nearshore to shallow shelf depositional facies. The transitionally succeeding dolomite interbedded with shale and marl in the Ribota Formation accumulated in a stable carbonate platform (Alvaro *et al.*, 1995), and in more offshore environments (in the upper part of the formation; Fig. 2). These sediments gradually pass into alternating shale and sandstone of the Huérmeda Formation deposited in a deeper distal portion of the platform. Similar lithology is observed in the lower part of the Daroca Formation and thus the sedimentary conditions. The arkosic sandstone interbeds, ranging from few centimetres to 9 meters in thickness (Figs. 2, 4; Gámez *et al.*, 1991) occur at several levels within the succession of alternating arkosic sandstone and shale in the upper Daroca Formation. The increased occurrence of current and wave sedimentary structures in the arkosic intervals indicate the high energy nearshore depositional conditions. Abundant and probably reworked specimens of trilobites attributed to the genus *Strenuaeva* and *Pseudolenus* (Liñán, pers. comm.) and unidentified brachiopods occur in the arkosic beds with planar cross stratification in the upper Daroca Formation (Fig. 4). The upper Daroca succession was interpreted to correspond to the Daroca regression and correlated with the Hawke Bay regression in Laurentia (Liñán and Gámez-Vintaned, 1993). These strata might be interpreted to record a shallowing up episode in the depositional basin but without an emergence or sedimentary break (in contrast to the Hawke Bay regression, Palmer and James, 1980). The basin was stabilized shortly after the deposition of the arkosic sandstone and a clastic-carbonate platform persisted, with monotonous accumulation of marl, shale and sandstone, throughout the deposition times of the succeeding Valdemiedes to Murero Formations. Formerly, the Valdemiedes Formation have been considered to record a terminal Early Cambrian extinction event (Liñán, Fernández-Nieto *et al.*, 1993; Liñán, Villas *et al.*, 1996).

The geological successions dealt with this study are located at the border of Soria and Zaragoza Provinces. The fossil record from the two localities include poorly preserved trilobites and inarticulate brachiopods (Figs. 2, 4; Liñán, pers. comm.), and here reported acritarchs (Figs. 3, 5).

Formation	Lithology	Samples	Trilobites	Gámez <i>et al.</i> 1991		This paper	
				Stage	Series	Acritarch Zones	Series
Murero		○ BO1-49/7	<i>Solenopleuropsis verdiagana</i> <i>Paradoxides (Ecc.) brachyrhachis</i>	CESARAUGUSTIAN	MIDDLE CAMBRIAN	No record	MIDDLE CAMBRIAN
		○ BO1-49/6 ○ BO1-49/4 ○ BO1-49/4 ○ BO1-49/3 ○ BO1-49/2 ○ BO1-49/1	<i>Paradoxides (Ecc.) sequeirosi</i> <i>Badulesia paschi</i> <i>Badulesia granieri</i>				
Mansilla			<i>Paradoxides (Ecc.) sulcatus</i> <i>Asturiaspis</i> sp.	LEONIAN			
Valdemiedes			<i>Paradoxides (Ecc.) mureroensis</i>				
Daroca		● BO1-41 ● BO1-40/7 ● BO1-40/6 ● BO1-40/5 ● BO1-40/4 ● BO1-40/3 ● BO1-40/1		BILBILIAN			
		● BO1-40 ● BO1-39/2 ● BO1-39/1 ● BO1-39					
		● BO1-37 ● BO1-36	<i>Protolenus (H.) temierelloides</i>				
		● BO1-35 ● BO1-34					
		● BO1-33 ● BO1-31 ● 92-5 ● 92-4 ● BO1-30T ○ BO1-28t ○ BO1-28 ○ BO1-27	<i>Strenuaeva incondita</i>				
Huérmeda				MARIANIAN			
Ribota							
Jalón	○ BO1-19		OVETIAN				
	○ BO1-13 ○ BO1-12 ○ BO1-10t ○ BO1-10 ○ BO1-8 ○ BO1-5 ○ BO1-1						
			LOWER CAMBRIAN		No record	LOWER CAMBRIAN	

**Figure 2.** The Borobia 1 section showing the stratigraphic position of the acritarch samples and occurrence of trilobites. Lithostratigraphy and faunal biostratigraphy is according to Gámez *et al.*, 1991, Liñán, *et al.*, 1992, and Álvaro and Liñán, 1997. The alternative level for the Lower-Middle Cambrian boundary is proposed on the basis of the acritarch occurrences. The Lower-Middle Cambrian boundary recognized by acritarchs is shown in the right column.



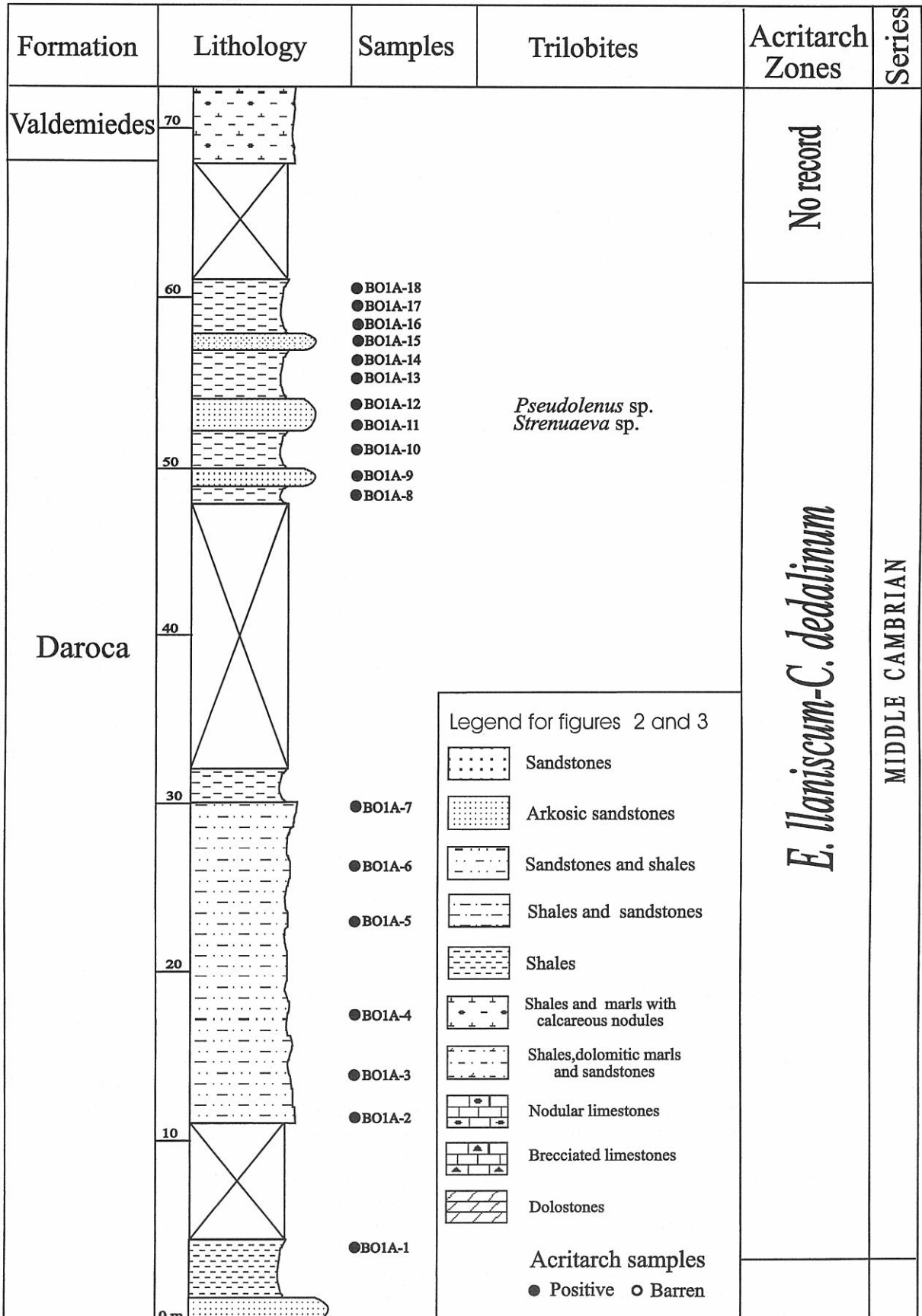


Figure 4. The Borobia 1A section, which is parallel and complementary to Borobia 1 section, showing the stratigraphic position of the acritarch samples and the occurrence of trilobite specimens. The Lower-Middle Cambrian boundary recognized by acritarchs is shown in the right column.



*Lophosphaeridium*, *Retisphaeridium* and *Eliasum*, though represented by single species within the association are biostratigraphically significant. Sphaeromorphic acritarchs are quantitatively dominant but lack biostratigraphic significance.

The stratigraphically lowest acritarch record in the Borobia succession derive from mudstone of the Ribota Formation in the interval containing trilobite *Strenuaeva incondita* Sdzuy, 1961 which is diagnostic for the Lower Cambrian Marianian regional Stage (Liñán, Perejón and Sdzuy, 1993; Figs. 2, 4). The acritarch assemblage is dominated by *Heliosphaeridium dissimulare*, *Skiagia ciliosa* and *Archaeodiscina umbonulata*, and other Early Cambrian species (Fig. 3) which display a remarkable morphological disparity. The assemblage occurs within a marine transgressive succession grading progressively from fine-grained clastic sediments (red-coloured sandstone and then shale) of the Jalón Formation into dolomite with microbial mats, oncolites and evaporites of the lower Ribota Formation (Gámez *et al.*, 1991; Alvaro *et al.*, 1995). The latter was deposited in littoral and marine nearshore environments. These strata subsequently pass into quite-water carbonate sediments with brachiopods, calcareous sponge spicules, echinoderms and trilobites in the upper Ribota Formation that are accumulated in sublittoral and more offshore environments. Samples from the upper Ribota Formation yielded few specimens of *Skiagia* but a considerable contents of particulate organic matter and coccoidal bacterial microfossils. This may suggest the existence of restricted circulation conditions in the sedimentary basin during the time of deposition of the upper Ribota Formation.

The microfossil assemblage from the Huérmeda Formation consists of 13 acritarch species (Figs. 2, 3), coccoidal bacterial and organic remains. The taxonomic diversity is slightly lower than in the lower Ribota Formation. The profuse accumulation of bacterial microfossils, organic matter and the presence of framboidal growth pseudomorphs of pyrite on the acritarch vesicles indicate a dynamic bacterial activity in the sediments and the prevalence of reduced conditions at the bottom zone of the depositional basin. The Huérmeda Formation comprises dark, kerogen-rich, laminated shale and alternation of shale and thin-bedded, fine-grained quartz sandstone. The lithology and organic facies of the formation and their succession within the entire marine sequence indicate a maximum flooding of the Early Cambrian transgression in the Borobia area.

Similar sedimentary conditions prevailed during the deposition of the lower part of the Daroca Formation. The same species as in the underlying strata are recorded, with a drastic decrease and even disappearance of the species of *Skiagia*, and three additional (e.g. *H. notatum*, *Tubulosphaera perfecta* n. sp. and *Leiosphaeridia bipyromifera* n. sp.) appear for the first time in this stratigraphic succession (Fig. 3). In the upper Daroca Formation is observed a shift in the depositional environments, with abundant reworked acritarchs from Huérmeda Formation (*Skiagia* species), that reflects the

increase of environmental energy. The shallower-water lithofacies progressively migrated over older, relatively deep-water deposits. The migration of coarser lithofacies in the upper Daroca Formation ceased and subsequently a carbonate-detrital platform environments developed and continued throughout Middle Cambrian in the area.

The taxonomic composition of the acritarch assemblages in the upper Daroca Formation is identical to the lower part of the formation, with exception of the species (*Celtiberium dedalinum*, *Eliasum llaniscum*, *Retisphaeridium dichamerum*, *Lophosphaeridium conicum* n. sp. and *Celtiberium* sp. A) that appeared in the succession for the first time (Figs. 3, 5). *C. dedalinum*, *E. llaniscum* and *R. dichamerum* are of a particular stratigraphic significance because their lowermost appearance marks the base of Middle Cambrian (see below). The continuous succession of the same acritarch species throughout the Daroca Formation, despite of the conspicuous change in the depositional environments, seems to imply rather uninterrupted marine sedimentation. This also suggests largely facies independent distribution of acritarchs within shallow shelf depositional settings in Cambrian (Moczydłowska and Vidal, 1992; Palacios and Vidal, 1992; Moczydłowska, in press).

## BIOSTRATIGRAPHY OF THE BOROBIA SUCCESSION

The global stratotype section for the Lower-Middle Cambrian boundary has not yet been established and various stratigraphic levels were recognized and/or proposed as standard candidates in different palaeogeographic areas (Bergström and Gee, 1985; Martin and Dean, 1988, Liñán, Fernández-Nieto *et al.*, 1993; Liñán, Perejón *et al.*, 1996; Young *et al.*, 1994; Geyer and Landing, 1995; Landing, 1995; Zhuravlev, 1995; Sdzuy *et al.*, 1996). The recognition of the regional boundaries is based on the occurrence of trilobite faunas that have mostly restricted geographic distribution and are often facies dependent. Their exact chronostratigraphic interregional correlation is thus uncertain (Geyer and Palmer, 1995; Moczydłowska *et al.*, 1996; Palmer, 1996).

The new acritarch record from the Cambrian of the Iberian Chains provides an useful and complementary mean for the biostratigraphy and, in particular, for the correlation irrespective of the faunal bioprovinces. The acritarch association from the Borobia sections consists of numerous taxa having well-defined stratigraphic ranges that are recognized in various occurrences and bound to the trilobite zones. The succession of acritarchs provides an alternative biozonation and make possible recognition of biochrones that are time equivalent to the faunal zones.

The Lower Cambrian rocks in the investigated area are sparsely fossiliferous. The Jalón Formation yielded only undiagnostic trace fossils. In other localities in the Iberian Chains poorly preserved trilobites from the



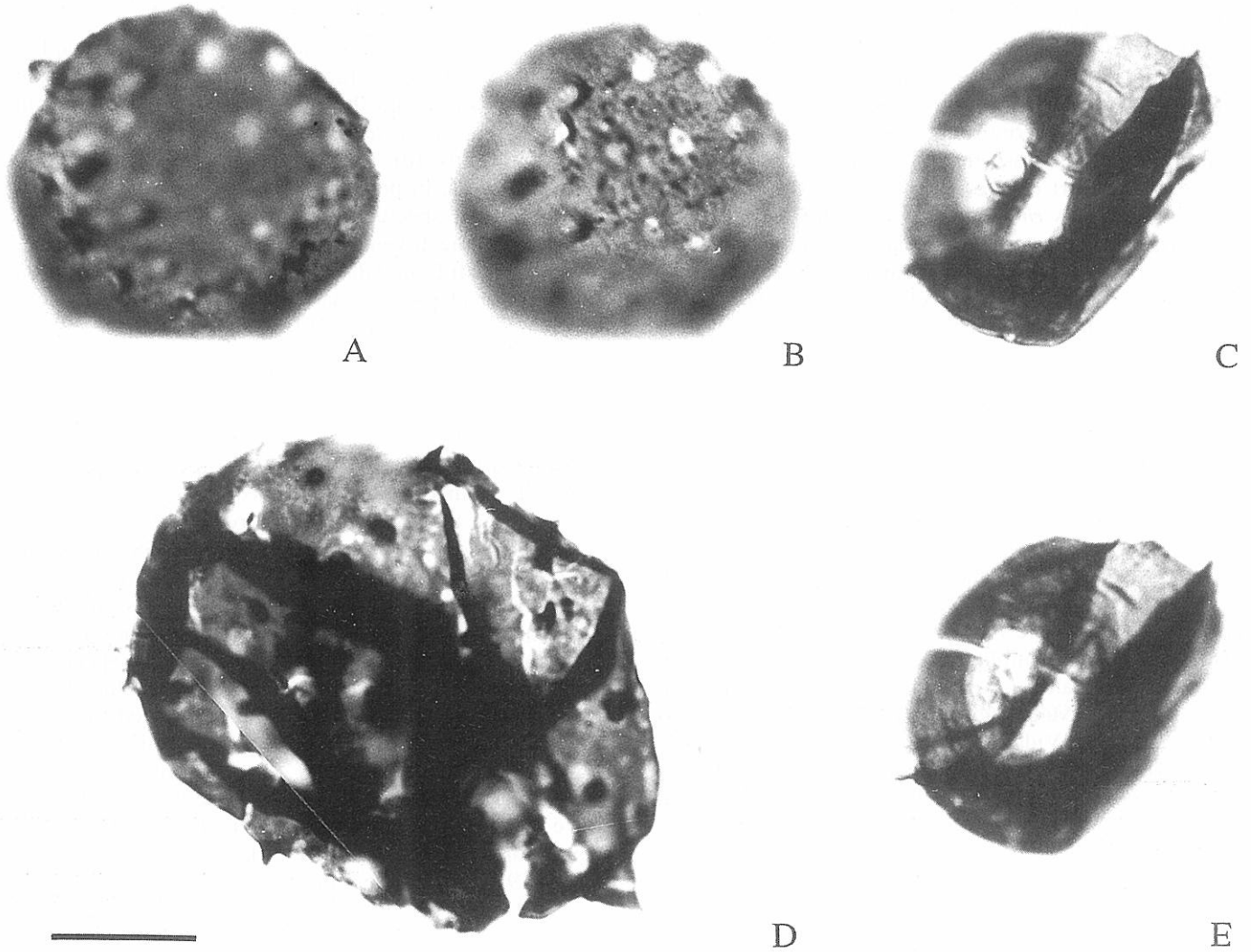
formation, attributed to *Dolerolenus* ? sp., *Anadoxides* ? sp. and *Thoralaspis* n. sp. A (Sdzuy, 1987), were considered to indicate the Lower Cambrian Ovetian regional Stage (Liñán, Perejón and Sdzuy, 1993). The stratigraphically lowermost occurrence of trilobites in the Borobia successions, assigned to *Strenuaeva incondita*, is in the lower part of the Ribota Formation (Fig. 2), whereas *Lusatiops ribonatus* and unidentified species of *Andalusiana*, *Kingaspis*, *Redlichia* and *Strenuaeva* have been reported elsewhere in the formation (Sdzuy, 1971a). The Ribota Formation was referred to the Marianian Stage (Liñán, Perejón and Sdzuy, 1993), and correlated with the Botoman regional Stage in Siberia (Liñán, Perejón *et al.*, 1996) though no trilobite species in common occur. Similar faunal assemblage, with additional species of *Micmacca* aff. *coloi* and *Kingaspis velatus*, were recovered in the Huérmeda Formation which was also referred to the Marianian Stage in its upper portion (Liñán, Perejón and Sdzuy, 1993). Acritarch assemblages deriving from the interval with *Strenuaeva incondita* in the Ribota Formation and from several levels in the Huérmeda Formation are characteristic to the *Heliosphaeridium dissimilare-Skiagia ciliosa* assemblage Zone that is recognized in Baltica, East Avalonia, Laurentia and Ibero-Armorica in northern Spain (Moczydłowska, 1991, in press; Palacios and Vidal, 1992; Vidal and Peel, 1993; Molyneux *et al.*, 1996). The latter zone is time equivalent to the *Holmia kjerulfi* assemblage Zone in Baltica (Moczydłowska, 1991; Ahlberg and Bergström, 1993). The correlation of the Ribota Formation with the *Holmia kjerulfi* Zone is, however, primarily supported by the occurrence of the genus *Strenuaeva* which is diagnostic for this zone (Bergström and Gee, 1985; Ahlberg, 1985; Ahlberg *et al.*, 1986; Moczydłowska, 1991). In the upper part of the Huérmeda Formation the trilobite species *Protolenus (H.) termierelloides* occurs (level Bo1-36, Fig. 2; Álvaro and Liñán, 1997). The upper part of the Daroca Formation contains the macrofossils *Strenuaeva* sp. and *Pseudolenus* sp. in the Borobia area (Fig. 4) (Liñán, pers. comm.), and an assemblage of trilobites “lacking olenellids”, and yet undescribed, was found in other localities in the lower portion of the formation (Sdzuy, 1971a; Liñán, Perejón and Sdzuy, 1993). This faunal record was assumed to be characteristic for the lower Bilbilian Stage in the Iberian Chains. The acritarchs obtained from the lower Daroca Formation are indicative of the *Volkovia dentifera-Liepaina plana* assemblage Zone that is time equivalent to the *Protolenus/Proampyx linnarssoni* trilobite Zone (Moczydłowska, 1991; Palacios and Vidal, 1992; Vidal and Peel, 1993; Ahlberg and Bergström, 1993). The upper Daroca Formation in both studied successions yielded an acritarch assemblage that is restricted to the transitional Lower-Middle Cambrian interval elsewhere, and additionally *Eliasium llaniscum*, *Celtiberium dedalinum* and *Retisphaeridium dichamerum* which are age-diagnostic for the Middle Cambrian (Figs. 3, 5). Their lower stratigraphic ranges coincide with the base of the Middle Cambrian (Staplin *et al.*, 1965; Fombella, 1977, 1978; Moczydłowska, in

press). The abundance occurring *Heliosphaeridium notatum* has been established in a short stratigraphic interval encompassing the uppermost Lower Cambrian *Protolenus* Zone and the lowermost Middle Cambrian *Acadoparadoxides oelandicus* Superzone (Volkova *et al.*, 1983; Hagenfeldt, 1989; Vidal and Peel, 1993; Moczydłowska, in press). The successive appearance of age-diagnostic species in the Borobia sections, first *H. notatum* in the lower Daroca Formation and then *E. llaniscum* with *C. dedalinum* followed by *R. dichamerum* in the upper Daroca Formation (Figs. 3, 5), records very accurately the Lower-Middle Cambrian boundary interval. The lowermost occurrence of *E. llaniscum* at the level of sample Bo1-40, (Figs. 2, 3) is taken to mark the base of the Middle Cambrian in the Borobia area. Previously, the Lower-Middle Cambrian boundary was recognized higher up in general stratigraphic succession of the Iberian Chains in the overlying Valdemiedes Formation at the level of the first record of *Paradoxides (Acadoparadoxides) mureroensis* Sdzuy, 1958 (Liñán and Gozalo, 1986; Liñán, Fernández-Nieto *et al.*, 1993; Liñán, Perejón *et al.*, 1996). Two faunal assemblages were distinguished in the Valdemiedes Formation, in its lower and upper portion, respectively. Several species of *Hamatolenus*, *Alueva* and *Perrector*? forming the “lower assemblage” of Valdemiedes, were interpreted to define the top of the Lower Cambrian Bilbilian Stage [*Hamatolenus (H.) ibericus* Zone; Liñán, Fernández-Nieto *et al.*, 1993]. However, any of the mentioned genus have stratigraphic range limited to Lower Cambrian, neither in the Iberian Chains (see Liñán, Fernández-Nieto *et al.*, 1993; Liñán, Perejón *et al.*, 1996) nor elsewhere (Young *et al.*, 1994). They occur also in Middle Cambrian and the *H. (H.) ibericus* species have only been referred in the Iberian Chains, thus per se, their use to recognize the top of Lower Cambrian is problematic.

Trilobite species of the “second assemblage” (e.g. stratigraphically younger) from the Valdemiedes Formation, consisting of Middle Cambrian age-diagnostic *Paradoxides*, among other less significant genera also included *Hamatolenus* (see full list of species in Liñán, Fernández-Nieto *et al.*, 1993; Liñán, Villas *et al.*, 1996), have been referred to the Leonian Stage at the base of Middle Cambrian. The proposed herein position of the Lower-Middle Cambrian boundary, based on the acritarch occurrence, is not in conflict with the trilobite record. It refines the boundary more precisely in this thick geological succession because of more abundant and dense distribution of largely facies independent phytoplanktonic microfossils that have been proven to be stratigraphically important elsewhere.

## SYSTEMATIC PALAEOLOGY

The new recognized species of organic-walled microfossils are referred to the informal group Acritarcha Evitt, 1963, and they are treated as form-species because of the uncertain biological affinities (Evitt, 1963; Fensome *et al.*, 1990). Some acritarch taxa are considered



**Figure 6.** Scale bar in D corresponds to 10  $\mu\text{m}$  for all photomicrographs. • A, B. *Celtiberium* sp. A, at two different focuses showing the shape of processes on the vesicle outline (A), and the perforation of the vesicle wall (B). Borobia, Bo1A-9/2:F/34. • C, E. *Leiosphaeridia bipyromifera* n. sp. Holotype at two focuses showing the upper surface of the vesicle with the minor pylome (C), and the lower surface with the major pylome (E). Borobia, Bo 1-39,/1:Y/33/4. • D. *Lophosphaeridium conicum* n. sp. Holotype. Borobia, Bo1A-9/1:W/34/1.

to belong to various divisions of green algae (e.g. Prasinophyta and others), and they probably represent different stages of their life cycle (Tappan, 1980; Martin, 1993; Colbath and Grenfell, 1994). Acritarchoous microfossils may also include unidentified and/or extinct protists (Mendelson, 1993) or even copepod egg-envelopes (Van Waveren, 1994; Van Waveren and Marcus, 1993). The form-taxa described here are arranged in the alphabetic order since they are not conformed to the natural systematics. Microscopic slides containing holotypes and all figured specimens are kept in the collections of the Área de Paleontología, Universidad de Extremadura, Badajoz (UEB.PAL-). The location of specimens is given by the England Finder coordinates following the number of sample and microscopic slide. Photomicrographs have been taken under the Nikon light transmitted microscope with the immersion oil and interference contrast.

#### Genus *Celtiberium* Fombella, 1977

**Type species:** *Celtiberium geminum* Fombella, 1977; pp. 117-118; pl. 1, figs. 10, 11; fig. 1:9; Spain, Cantabrian Mountains, Oville Formation, Middle Cambrian.

#### *Celtiberium* sp. A Figs. 6A, 6B

**Material:** A single, relatively well-preserved specimen.

**Description:** Organic-walled microfossil with spherical, single-layer vesicle, circular in outline, bearing few short processes. The processes are hemispheric-like or slightly conical with distal terminations closed and rounded; they are hollow inside and freely communicating with the internal cavity of the vesicle. The vesicle wall is psilate, thin, translucent and perforated by pores that are arranged around

the processes. Only three processes are preserved on the visible vesicle surface but scars after those broken apart are clearly observable showing an even distribution of the processes on the vesicle. The vesicle diameter is 26  $\mu\text{m}$ , process length and width is around 2  $\mu\text{m}$ .

**Present record:** Clayey, organic-rich matrix of arkosic sandstone in the upper part of the Daroca Formation, previously referred to the upper Lower Cambrian (Liñán, Perejón and Sdzuy, 1993), and here regarded as the lowermost Middle Cambrian.

Genus *Leiosphaeridia* Eisenack, 1958, emend. Downie and Sarjeant, 1963

**Type species:** *Leiosphaeridia baltica* Eisenack, 1958; p. 8; pl. 2, fig. 5; Estonia, Ordovician (Ashgill).

*Leiosphaeridia bipylomifera* Palacios, n. sp.  
Figs. 6C, 6E

**Holotype:** Specimen UEB.PAL-Bo1-39,/1:Y/33/4 (Fig. 6C, 6E).

**Locus typicus:** NE Spain, northwestern area of the Eastern Iberian Chain, Province of Soria, Borobia 1 section.

**Stratum typicum:** Alternating grey mudstone and fine-grained sandstone in the lower part of the Daroca Formation, referred to the upper Lower Cambrian (Liñán, Perejón and Sdzuy, 1993), and here also regarded as the uppermost Lower Cambrian.

**Derivatio nominis:** From Latin *bi* (=two), and classical Greek *πυλωμα*, *-ατος* (=opening, pylome), referring to the two pylomes of the vesicle.

**Material:** Three relatively well-preserved specimens.

**Diagnosis:** The vesicle originally spherical, circular to ovoidal in outline after compression, with psilate wall surface, displaying two circular pylomes of different diameter that are located on the opposite sides of the vesicle.

**Dimensions:** N=3. The vesicle diameter ranges 20-26  $\mu\text{m}$  (holotype 20x26  $\mu\text{m}$ ), diameter of the bigger pylome is 8 to 11  $\mu\text{m}$ , diameter of the smaller pylome is 4 to 5  $\mu\text{m}$ .

**Remarks:** The outlines of pylomes are circular to semicircular due to the compaction and they might be seen as superimposed within each other. The compression folds are present on the vesicle surface. This is the first record of acritarch with two pylomes. Leiosphaerids with a single pylome were previously described from various occurrences (Martin and Dean, 1981).

**Stratigraphic range and occurrence:** As for the holotype, and SW Spain, Ossa-Morena Zone, Zafra area, La Albuera

del Castellar section, La Lapa Formation, Vallehondo Member, uppermost Lower Cambrian.

Genus *Lophosphaeridium* Timofeev, 1959 ex Downie, 1963, emend. Lister, 1970

**Type species:** *Lophosphaeridium rarum* Timofeev, 1959 ex Downie, 1963; p. 630 (= *Lophosphaeridium rarum* Timofeev, 1959; p. 29; pl. 2, fig. 5; pl. 24, fig. 2); Russia, "Glauconic beds", lower Ordovician.

*Lophosphaeridium conicum* Palacios, n. sp.  
Fig. 6D

**Holotype:** Specimen UEB.PAL-Bo1A-9/1:W/34/1 (Fig. 6D).

**Locus typicus:** NE Spain, northwestern area of the Eastern Iberian Chain, Province of Soria, Borobia 1A section.

**Stratum typicum:** Clayey, organic-rich matrix of arkosic sandstone in the upper part of the Daroca Formation, previously referred to the upper Lower Cambrian (Liñán, Perejón and Sdzuy, 1993), and here regarded as the lowermost Middle Cambrian.

**Derivatio nominis:** From Latin *conus*, *-i* (=cone, apex), referring to the process shape.

**Material:** A single well-preserved specimen.

**Diagnosis:** The vesicle originally spherical, oval in outline after compaction, bears robust and evenly distributed short ornamentation elements in shape of thorns that are solid.

**Dimensions:** The vesicle diameter is 32x42  $\mu\text{m}$ , the thorn length is 3-4  $\mu\text{m}$  and their width at the base is 2-4  $\mu\text{m}$ .

**Stratigraphic range and occurrence:** As for the holotype.

Genus *Tubulosphaera* Palacios, n. gen.

**Type species:** *Tubulosphaera perfecta* Palacios, n. sp.

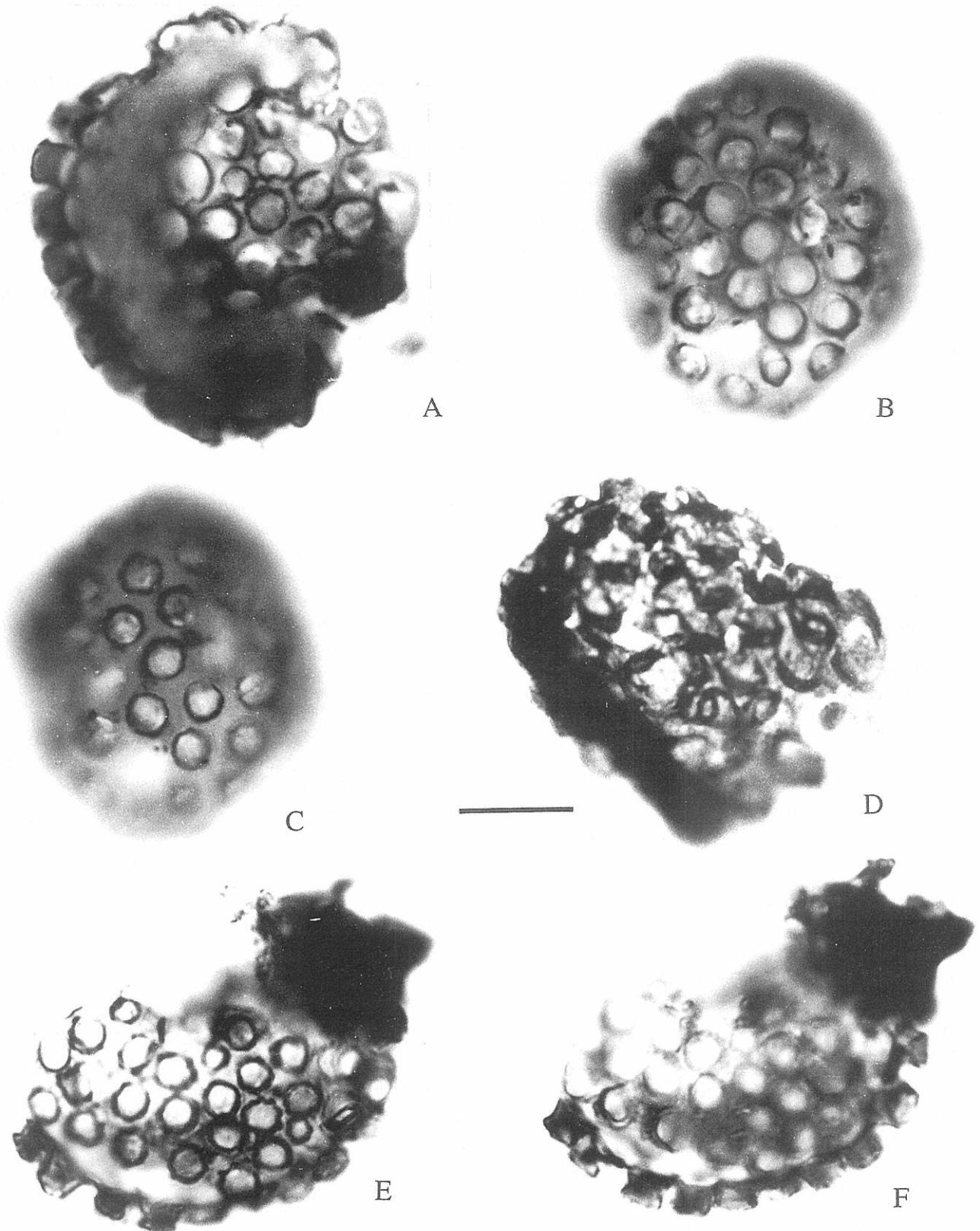
**Derivatio nominis:** From Latin *tubulus*, *-i* (=small tube), and *sphaera*, *-ae* (=sphere), referring to the spherical vesicle bearing processes tubular in shape.

**Diagnosis:** As for the type species.

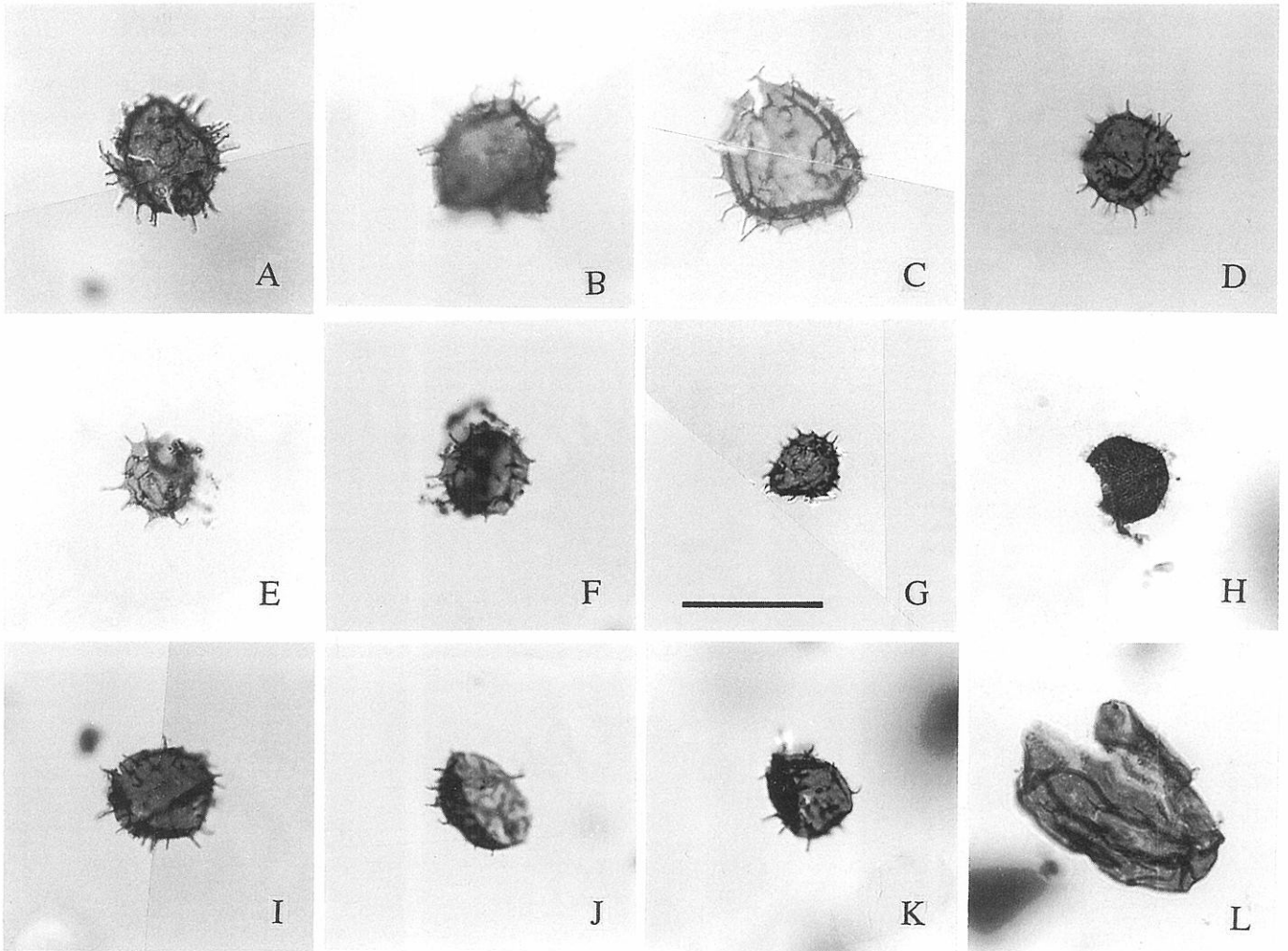
*Tubulosphaera perfecta* Palacios, n. sp.  
Fig. 7

1990? *Celtiberium* sp.; Eklund, 25, fig. 9L.

**Holotype:** ? *Celtiberium* sp., Specimen LO 5945, slide Ög81-51:1/U39-3 (Collection of Lund University, Geology Department, Sweden), Eklund (1990: 25, fig. 9L).



**Figure 7.** *Tubulosphaera perfecta* Palacios n. sp. Scale bar in D corresponds to 10  $\mu\text{m}$  for all photomicrographs. • A-C. Three-dimensionally, exceptionally well preserved lectotype shown at various focus levels. La Albuera del Castellar, Zafra, C90-31/1:P/40. • D. Poorly preserved specimen with collapsed edges of the process terminations. Borobia, Bo1-39./2:M/38/4. • E, F. Fragment of the specimen with less well preserved processes displaying the initial taphonomic deformation of their regular tubular shape, as seen in the outline of the vesicle. The circular sections of the processes become also deformed and crenulated, as observed in the polar view on the vesicle surface. The same specimen at two focus levels. La Albuera del Castellar, Zafra, C90-31/1:Y/4 1.



**Figure 8.** Scale bar in G corresponds to 20  $\mu\text{m}$  for all photomicrographs. • A-D. *Heliosphaeridium notatum* (Volkova, 1969) Moczydłowska, 1991. • A. Borobia, Bo1-40:Q/30/2. • B. Borobia, Bo1A-9/2:N/49/1. • C. Borobia, Bo1-39/2:G/41/3. • D. Borobia, Bo1A-15:E/33/3. • E, F. *Heliosphaeridium obscurum* (Volkova, 1969) Moczydłowska, 1991. • E. Purujosa, Ribota Formation, Pu-4:T/34/1. • F. Borobia, Bo1A-9:O/49/3. • G. *Asteridium spinosum* (Volkova, 1969) Moczydłowska, 1991. Purujosa, Huérmeda Formation, Pu-25:Q/27/2. • H. *Asteridium lanatum* (Volkova, 1969) Moczydłowska, 1991. Borobia, Bo1-39-2:J/33/1/3. • I-K. *Heliosphaeridium oligum* (Jankauskas, 1976) Moczydłowska, in press. • I. Borobia, Bo1A-9:N/49/11. • J. Borobia, Bo1A-6:S/44. • K. Borobia, Bo1A-14:Z/35. • L. *Eliasum llaniscum* Fombella, 1977. Borobia, Bo1A-9:T/41.

**Locus typicus:** Sweden, Östergötland, Bårstad 2 borehole (Eklund, 1990: 20-21, fig. 1).

**Stratum typicum:** Glauconite sandstone in the informal “glauconite sandstone” member in the File Haidar Formation, the Bårstad 2 borehole at the depth of 48.5 m and 49.0 m; Middle Cambrian, *Eccaparadoxides insularis* Zone (Eklund, 1990: 21-23).

**Derivatio nominis:** From Latin *perfectus*, *-a*, *-um* (=perfect, excellent, complete), referring to the very regular and exuberant morphology of the processes.

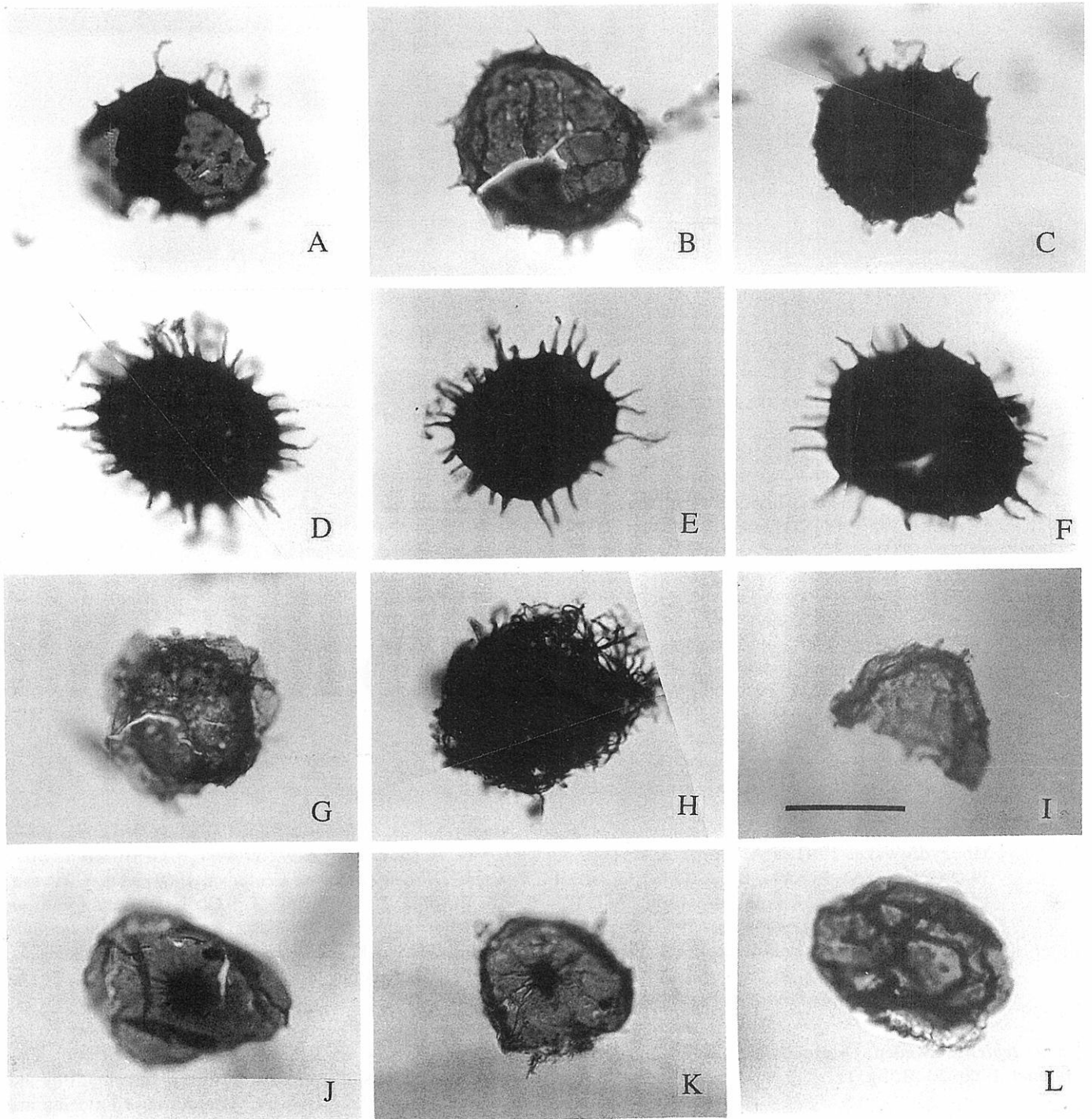
**Material:** Approximately hundred of well-preserved and three-dimensionally preserved specimens.

**Diagnosis:** Spherical vesicle bearing abundant and closely arranged regular processes in shape of tubes that

may be slightly widened at the distal portion. The processes are distally closed and their terminations are flat or only slightly convex. The process cavities are freely connected with the vesicle interior. The distal edge of the processes is circular in outline that is visible in the polar view.

**Dimensions:** N=50. The overall vesicle diameter with processes ranges 25-45  $\mu\text{m}$ , the vesicle diameter is 20-37  $\mu\text{m}$ , the process length is 3-4  $\mu\text{m}$ , the width of process bases is 2-4  $\mu\text{m}$ , and the width of process terminations is 2-5  $\mu\text{m}$ .

**Remarks:** The specimen described from Sweden under an open nomenclature as *?Celtiberium* sp. (Eklund, 1990), is chosen herein to be the holotype of the new species. Though lacking the palaeontological description the Swedish specimen is very well preserved, illustrated



**Figure 9.** Scale bar in I corresponds to 25  $\mu\text{m}$  for all photomicrographs. • A-C, F. *Skiagia ciliosa* (Volkova, 1969) Downie, 1982. • A. Borobia, Bo1-37/1:N/50. • B. Borobia, Bo1-92-5:Y/41. • C. Borobia, Bo1A-6:K/38. • F. Borobia, Bo1A-13:M/31/3. • D, E. *Skiagia compressa* (Volkova, 1968) Downie, 1982. • D. Borobia, Bo1A-2/1:G/37/1. • E. Borobia, Bo1A-3:M/31/3. • G. *Granomarginata squamacea* Volkova, 1968. Borobia, Bo1-92-5/2:U/44/2. • H. *Comasphaeridium longispinosum* Hagenfeldt, 1989. Borobia, Bo1-92-4/1:V/26/4. • I. *Celtiberium dedalinum* Fombella, 1978. Borobia, Bo1A-2/2:S/31. • J, K. *Archaeodiscina umbonulata* Volkova, 1968. • J. Borobia, Bo1-95-5/2:S/45/4. • K. Borobia, Bo1-95/2:M/39. • L. *Retisphaeridium dichamerum* Staplin, Jansonius and Pocock, 1965. Borobia, Bo1-40:G/39/1.

and it is in the same dimensional range (Eklund, 1990: fig. 9L), and no doubt it represents the first record of the new species. The stratigraphic position of the holotype is defined by the occurrence of trilobites within the

succession that are age-diagnostic for the basal Middle Cambrian *Acadoparadoxides oelandicus* Superzone in Scandinavia and East Avalonia (Eklund, 1990; Young *et al.*, 1994; Moczydłowska, in press).

**Stratigraphic range and occurrence:** As for the holotype in Sweden: Östergötland, Bårstad 2 borehole, File Haidar Formation, "oelandicus" beds (Eklund, 1990). And the present record comprising: NE Spain, Iberian Chains, Borobia area, lower portion of the Daroca Formation (sample 39/1), the upper part of Lower Cambrian (Liñán, Perejón and Sdzuy, 1993), and SW Spain, Ossa-Morena Zone, Zafra area, La Albuera del Castellar section, uppermost portion of the Vallehondo member of La Lapa Formation (upper part of Lower Cambrian) and lower portion of Playón beds, Middle Cambrian (Liñán *et al.*, 1995; Moczydłowska *et al.*, 1996) that are considered here the time equivalent to the *Acadoparadoxides oelandicus* Superzone (sample C-90-31/1:P/40).

## CONCLUSIONS

The taxonomically diverse acritarch association from the Borobia successions provides a new mean for the biostratigraphic subdivision of the Lower Cambrian in the Iberian Chains and the recognition of the Lower-Middle Cambrian boundary. Three distinguished stratigraphically succeeding microfossil assemblages are characteristic for the Lower Cambrian *Heliosphaeridium dissimulare-Skiagia ciliosa* and *Volkovia dentifera-Liepaina plana* acritarch zones, and the informal lowermost Middle Cambrian acritarch assemblage. These zones correspond to the *Holmia kjerulfi*, *Protolenus* and *Acadoparadoxides oelandicus* trilobite zones respectively, and can be alternatively applied to define the chronostratigraphic equivalence of the strata from various faunal bioprovinces. The acritarch-based recognition of the Lower-Middle Cambrian boundary in the Daroca Formation, stratigraphically below the level previously assigned by trilobite faunas, may imply the need for re-evaluation of the boundary interval in other regions of the Iberian Peninsula. However, the newly proposed position for the boundary allows to correlate more precisely the geological successions between Iberia, Baltica and East Avalonia.

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