

# Calpionellid distribution and microfacies across the Jurassic/Cretaceous boundary in western Cuba (Sierra de los Órganos)

RAFAEL LÓPEZ-MARTÍNEZ<sup>1,✉</sup>, RICARDO BARRAGÁN<sup>1</sup>, DANIELA REHÁKOVÁ<sup>2</sup> and JORGE LUIS COBIELLA-REGUERA<sup>3</sup>

<sup>1</sup>Instituto de Geología, Universidad Nacional Autónoma de México, Ciudad Universitaria, Delegación Coyoacán, C.P. 04510, México D.F., México; ✉rafaelopez83@hotmail.com

<sup>2</sup>Comenius University, Faculty of Natural Sciences, Department of Geology and Paleontology, Mlynská dolina G, 842 15 Bratislava, Slovak Republic; rehakova@fns.uniba.sk

<sup>3</sup>Departamento de Geología, Universidad de Pinar del Río, Martí # 270, Pinar del Río, C.P. 20100, Cuba

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**Abstract:** A detailed bed-by-bed sampled stratigraphic section of the Guasasa Formation in the Rancho San Vicente area of the “Sierra de los Órganos”, western Cuba, provides well-supported evidence about facies and calpionellid distribution across the Jurassic/Cretaceous boundary. These new data allowed the definition of an updated and sound calpionellid biozonation scheme for the section. In this scheme, the drowning event of a carbonate platform displayed by the facies of the San Vicente Member, the lowermost unit of the section, is dated as Late Tithonian, Boneti Subzone. The Jurassic/Cretaceous boundary was recognized within the facies of the overlying El Americano Member on the basis of the acme of *Calpionella alpina* Lorenz. The boundary is placed nearly six meters above the contact between the San Vicente and the El Americano Members, in a facies linked to a sea-level drop. The recorded calpionellid bioevents should allow correlations of the Cuban biozonation scheme herein proposed, with other previously published schemes from distant areas of the Tethyan Domain.

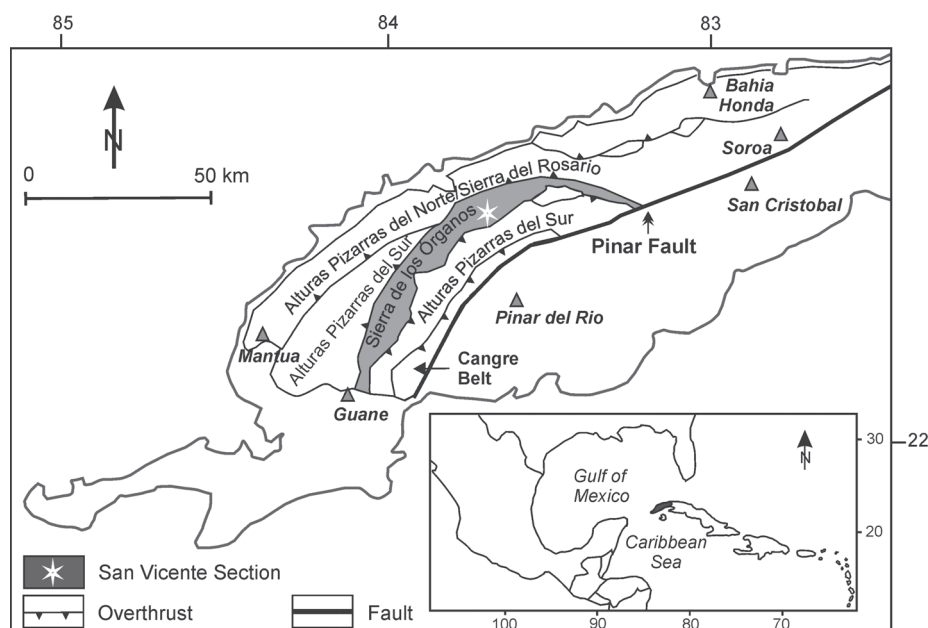
**Key words:** Jurassic/Cretaceous boundary, Cuba, calpionellid biostratigraphy, microfacies, drowned platform, storm deposits.

## Introduction

The location of Cuba within the Caribbean plate, offers a good point of reference to compare and establish links between the geological and biological processes in the Eastern and Western Tethys during the Mesozoic, particularly those at the Jurassic–Cretaceous interval. Several good successions of the Tithonian/Berriasian boundary interval of western Cuba are well-exposed in the Pinar del Río Province. They are essentially recorded on the Guasasa Formation, a typical unit of the San Vicente stratigraphic section at “Sierra de los Órganos” orogenic belt (Fig. 1).

Pioneering works on the definition of the Jurassic/Cretaceous boundary in western Cuba on the basis of ammonites, calpionellids and other microfossils were focused on stratigraphic sections across the “Sierra de los Órganos”. The first contribution was by Brönnimann in 1954. Since then, several authors have con-

tributed to the topic, especially Furrázola-Bermúdez & Kreisel (1973), who recognized the presence and stratigraphic distribution of the *Crassicollaria* and *Calpionella* Zones in some sections of western Cuba, and reported a new species of *Chitinoidea*. However, in their study, they did not pro-



**Fig. 1.** Map showing the location of the Rancho San Vicente stratigraphic section and the main tectonic units and structures of western Cuba. Modified from Cobiella-Reguera & Olóriz (2009).

duce sound data to establish the Jurassic/Cretaceous boundary in Cuba by means of calpionellids. Later, Pop (1976) analysed three sections in the “Sierra de los Órganos” belt defining calpionellid zones and concluded that the Jurassic/Cretaceous boundary in this area could be established at the base of the *Calpionella* Zone. Pszczółkowski (1978) subdivided the Guasasa Formation into four members, namely in stratigraphic order: San Vicente, El Americano, Tumbadero and Tumbitas. That author placed the contact between the San Vicente and El Americano Members as coincident with the Kimmeridgian/Tithonian boundary, whereas the contact between the El Americano and Tumbadero Members was conceived as coincident with the Tithonian/Berriasian boundary. Myczyński & Pszczółkowski (1990) kept the El Americano/Tumbadero contact as coincident to the Tithonian/Berriasian boundary on the basis of ammonites and microfossils. However, Fernández-Carmona (1998) in his unpublished Doctoral Thesis placed the Tithonian/Berriasian boundary within the uppermost strata of the El Americano Member. Afterwards, Pszczółkowski & Myczyński (2003) pursued and accepted that idea for some sections in western Cuba.

Pszczółkowski et al. (2005) identified calpionellid and radiolarian zones in western Cuba and correlated them with ammonite zones from the western Tethys. The last relevant contribution to this topic in western Cuba is by Pszczółkowski & Myczyński (2010), who analysed calpionellid and ammonite assemblages, but no differences in age of the members of the Guasasa Formation, neither the stratigraphic position of the Jurassic/Cretaceous boundary within the unit were reported.

The present contribution focuses on calpionellid biostratigraphy from the San Vicente to Tumbadero Members within the Guasasa Formation in the San Vicente Section of the “Sierra de los Órganos”. In order to specify the age of the limits between its members, and to establish a reliable position of the Tithonian/Berriasian boundary within the unit, this work was based on a high resolution sampling.

### Regional geological setting

According to Iturralde-Vinent (1997), the stratigraphy of Cuba can be differentiated into two main domains associated with different geological histories: the foldbelt (Early-Middle Jurassic to Late Eocene) and the neoautochthonous. The foldbelt is composed of elements detached from several old tectonic plates, while the neoautochthonous was formed in the North America Passive Margin after the accretionary process that led to the formation of the foldbelt.

The nappe pile of the Guaniguanico Cordillera (Hatten 1967; Khudoley & Meyerhoff 1971; Piotrowska 1978; Pszczółkowski 1978, 1994) is a great lens-shaped antiform with five main tectonic sheets, each one with its own stratigraphic sections (Cobiella-Reguera 2008). Pszczółkowski & Myczyński (2010) referred to this nappe pile as the “Guaniguanico megaunit” in which the Sierra de los Órganos occupies the lowest structural position, whereas the Sierra del Rosario unit contains the uppermost nappes (Fig. 1).

In previous works the Mesozoic paleomargin sections in the Guaniguanico Cordillera were considered as exotic crustal

blocks or terranes (Iturralde-Vinent 1997; Pszczółkowski 1999) detached from the Maya Block. In the opinion of other authors, a good correlation between the Mesozoic sections in the southeastern Gulf of Mexico and western Cuba sheds new light on the idea of an original juxtaposition between both domains (Moretti et al. 2003; Cobiella-Reguera & Olóriz 2009). However, Saura et al. (2008) considered western Cuban facies as a distal expression of the development of the Bahamas-Florida margin.

### Lithostratigraphy

The rock sequences of the Jurassic-Cretaceous boundary transition in western Cuba are exposed in the “Sierra de los Órganos”, and recognized within the facies of the Guasasa Formation (Pszczółkowski 1978, 1999). This unit defined by Herrera (1961) was subdivided by Pszczółkowski (1978) into four members, which are named in stratigraphic order as San Vicente, El Americano, Tumbadero and Tumbitas (Fig. 2). Pszczółkowski & Myczyński (2010), correlated the members with ammonites and calpionellid biostratigraphy as shown on Fig. 3. In the section we studied, the upper part of the San Vicente, the whole El Americano and Tumbadero and the lowermost part of the Tumbitas Members are recorded.

#### *San Vicente Member*

This unit is of Kimmeridgian–Early Tithonian age according to Pszczółkowski & Myczyński (2010), and is mainly composed by massive thick-bedded shallow-water carbonates. A diagnostic feature of this unit is represented by partially dolomitized limestones at the top. The fossils recorded within this unit, mainly consist of *Nerinea* sp., Textulariidae (Pszczółkowski 1978), miliolids, and scarce calcareous dinocysts (Fernández-Carmona 1998).

#### *El Americano Member*

It is composed of thin-bedded limestones with shaly interbeds. The fossil record includes calpionellids and ammonites in the topmost Tithonian and in the Berriasian (Fernández-Carmona 1998; Pszczółkowski et al. 2005).

#### *Tumbadero Member*

It is represented by thin-bedded limestones of Middle-Late Berriasian age with very thin cherty beds and lenses. A rich association of radiolarians and calpionellids indicates the pelagic origin of the limestones of this member (Pszczółkowski & Myczyński 2003).

#### *Tumbitas Member*

It is mainly composed of thick-bedded, light microgranular limestones, with a few clay interbeds. The field diagnostic criteria to discriminate the Tumbadero and the Tumbitas Members are the disappearance of the cherty lenses and the light colour of the limestones. The stratigraphic section studied in this work includes only a small lower part of this member.

Area		Sierra de los Órganos		Sierra del Rosario Alturas Pizarras del Norte Esperanza	
Age					
Berriasian	U	Tumbitas Member		Polier Formation	
	M	Tumbadero Member		Sumidero Member	
	L				
Tithonian		El Americano Member		Artemisa Fm	
Kimmeridgian		San Vicente Member		La Zarza Member	
Oxfordian		Pimienta Member		Francisco Formation	
U	Jagua Fm	Jagua Vieja Member		El Sabalo Formation	
		Pan de Azúcar Member	Zacarías Member		
M		Upper San Cayetano Formation		Upper San Cayetano Formation	

Fig. 2. Correlation of Upper Jurassic and Berriasian lithostratigraphic units between the main tectonic domains of western Cuba. Modified from Cobiella-Reguera & Olóriz (2009).

### Materials and methods

The present research focuses on the stratigraphic interval from the topmost part of the San Vicente to the topmost part of the Tumbadero Members. The sampling was done on a bed-by-bed basis, including inter-layers. The samples RSV A–M correspond to the San Vicente Member, RSV 1–95 to the El Americano Member, and RSV 95–145 to the Tumbadero Member (see Fig. 9 for detailed samples position).

### Biostratigraphic results

#### Early Tithonian Semiradiata dinocyst Zone (Samples RSV A–M)

These samples at the top of the San Vicente Member correspond to the lower part of the studied section (Fig. 9). In thin section the rocks are characterized as poorly sorted and washed wackestones (occasionally non-fossiliferous mudstones) of intraclasts, peloids and pellets, alternating with peloidal packstones (Fig. 4A). The main skeletal particles are benthic foraminifers, favreïnids, gastropods, green algae, ostracods and scarce bryozoans. Some samples are partially dolomitized with euhedral dolomitic crystals; bioturbation is abundant principally due to incrustation. The rock displays cloudy structure in thin section due to microbial activity. Biostratigraphic indicators are very scarce and the age of the member was determined only by the presence of a few *Cadosina semiradiata* Wanner (Fig. 4B) which could determine the Early Tithonian Semiradiata dinocyst Zone *sensu* Reháková (2000a).

#### Late Tithonian Chitinoïdella Zone

##### Boneti Subzone (Samples RSV 1–5)

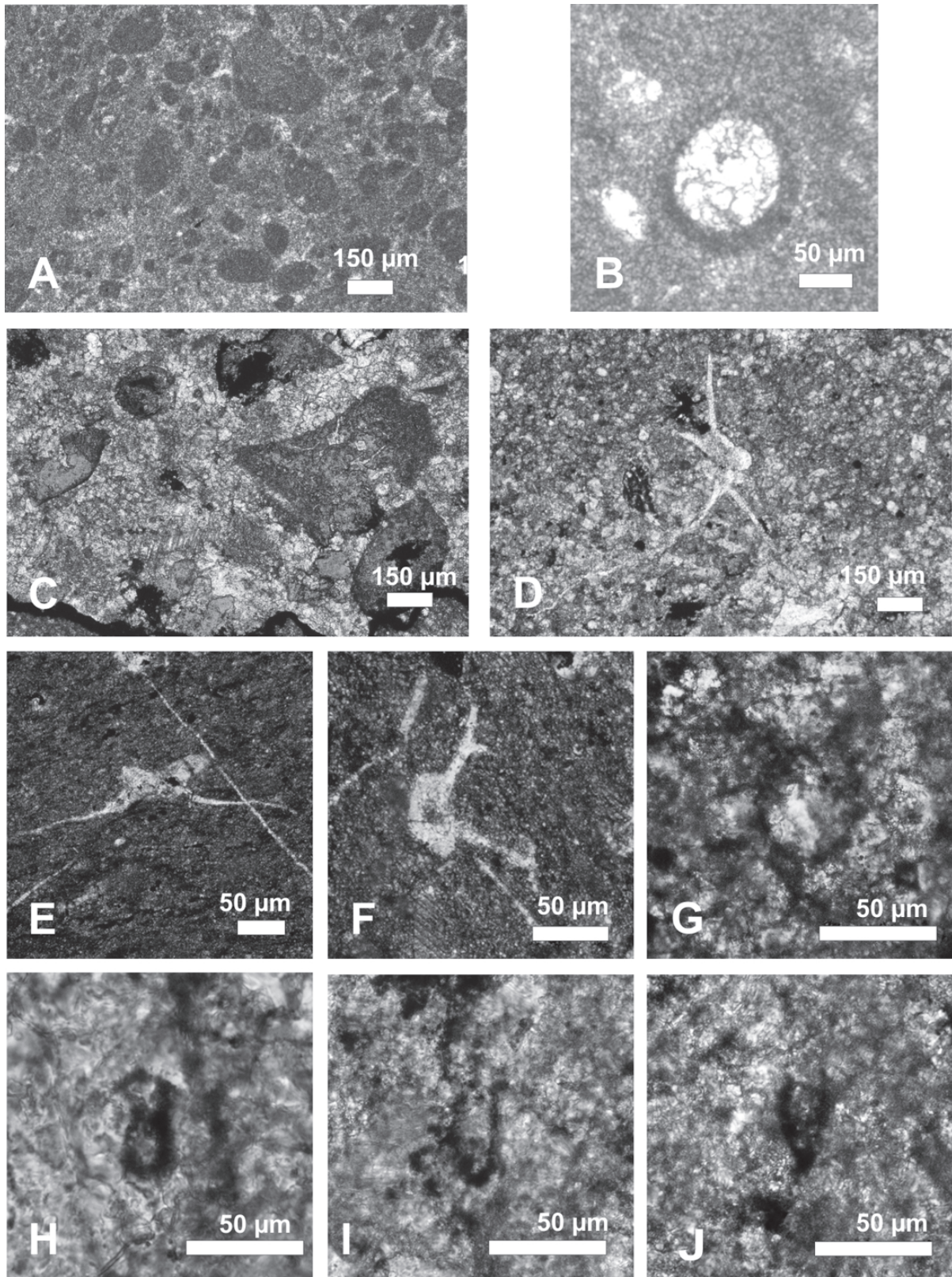
These rock samples from the very base of the El Americano Member (Fig. 9) consist of saccocomid mudstones to packstones with less abundant filaments, glauconitic grains, few gastropods and echinoids (Fig. 4C–F). This interval is characterized by the presence of *Chitinoïdella* along with other genera displaying microgranular calcitic walls looking dark under a transmitted light microscope. The *Chitinoïdella* Zone is divided into two subzones namely from bottom to top as Dobeni and Boneti Grandesso (1977), Borza (1984). In the analysed section only chitinoïdellids of Boneti Subzone were found.

Specimens of Chitinoïdellidae are scarce, being represented only by a few poorly preserved specimens of *Chitinoïdella boneti* Doben (Fig. 4G), *Longicollaria* sp. (Fig. 4H), *Daciella* sp. (Fig. 4I) and *Daciella danubica* Pop (Fig. 4J). The state of preservation prevents observation of diagnostic features of most of the specimens of this family. The matrix is always microsparitic and masks other possible markers.

Nonetheless, this assemblage and the presence of *Chitinoïdella boneti* Doben, provide a good point to identify the Boneti Subzone *sensu* Borza (1984). The absence of the underlying Dobeni Subzone is explained by paleoecological reasons due to the shallow-water conditions prevailing before the drowning of the San Vicente carbonated bank.

Guasasa Fm Members	Calpionellid biozonation		Ammonite biozonation
Tumbitas Member	Calpionellites	Major	Not recognized ammonite biozonation
		Darderi Murgeanui	
Tumbadero Member	Calpionellopsis	Oblonga	
		Simplex	
	Calpionella	Elliptica	
		Alpina	
El Americano Member	Crassicollaria	Intermedia	
		Remanei	
	Chitinoïdella	Boneti	
		Dobeni	
Saccocoma	Colomisphaera spp. Cadosina parvula	<i>Vinalesites-Protancyloceras</i>	
		<i>Durangites, Salinites and Proniceras</i>	
San Vicente			<i>Paralytohoplites caribeus</i>
			<i>Pseudolissoceras</i> spp.– <i>Virgatosphinctes</i> spp.
			<i>Hybonoticeras–Mazapilites</i>

Fig. 3. Calpionellid and ammonite biostratigraphy of the Rancho San Vicente section according to Pszczółkowski & Myczyński (2010).



**Fig. 4.** Photomicrographs of thin-sections of the San Vicente and the lower part of the El Americano Members. **A** — Poorly sorted peloid packstone-wackestone with micro-sparitic matrix. San Vicente Member, sample RSV-B; **B** — *Cadosina semiradiata semiradiata* Wanner. Sample RSV-A; **C** — Glauconitic grains from the base of the El Americano Member. Sample RSV-1.2; **D-F** — Differently orientated sections of *Saccocoma* sp. Sample RSV-5; **G** — *Chitinoidella boneti* Doben. Sample RSV-2; **H** — *Longicollaria* sp. Sample RSV-3; **I** — *Daciella* sp. Sample RSV-5; **J** — *Daciella danubica* Pop. Sample RSV-4.

The Boneti Subzone has been recorded with a similar assemblage from Cuba (Kreisel & Furrázola-Bermúdez 1971; Furrázola-Bermúdez & Kreisel 1973), Mexico (Lugo 1975), Western Balkanides (Bakalova 1977; Lakova 1993), Western Carpathians (Borza 1984; Reháková & Michalík 1997), Northwestern Anatolia (Altiner & Özkan 1991) and Eastern Alps (Reháková 2002).

#### *Late Tithonian Crassicollaria Zone (Samples RSV 6–22)*

An abrupt change in the facies occurs in this part of the section still within the base of the El Americano Member (Fig. 9). The *Saccocoma* packstones are replaced by wackestones with sponges, radiolarians, calpionellids, filaments and scarce resedimented gastropods and bryozoans (Fig. 5A,B). In addition intercalations of grainstones to rudstones appear. The calcareous dinocysts are scarce and represented by *Stomiosphaerina proxima* Rěhánek (Fig. 5C,D). The calpionellid association consists of the *Crassicollaria* and *Tintinnopsella* and is represented by *Crassicollaria colomi* Doben (Fig. 5E), *Crassicollaria parvula* Remane (Fig. 5F), *Crassicollaria massutiniana* (Colom) (Fig. 5G), *Crassicollaria brevis* Remane (Fig. 5H), *Crassicollaria intermedia* Durand-Delga (Fig. 5I), *Tintinnopsella remanei* (Borza) (Fig. 5J), and small *Tintinnopsella carpathica* (Murgeanu & Filipescu) (Fig. 5K). The *Calpionella* is scarce and recorded only in the topmost part of the zone. The large forms such as *Calpionella grandalpina* Nagy and *Calpionella elliptalpina* Nagy were not found.

This interval is characterized by the taphonomic and sedimentary condensation. The evidence of this condensation is expressed by the mixture of different subzones of *Crassicollaria* Zone and glauconitic grains. This condensation prevents the subdivision of *Crassicollaria* Zone in the studied section.

The topmost part of this interval is marked by storm deposits characterized by grainstones of peloids and resedimented shallow-water fossils similar to those illustrated in Fig. 6 (A,B).

#### *Early Berriasian Calpionella Zone*

##### *Alpina Subzone (Samples RSV 23–38)*

The acme of small spherical forms of *Calpionella alpina* Lorenz (Fig. 6C–E) marks a change in the assemblage composition and defines the base of the *Calpionella* Zone, its *Alpina* Subzone (*sensu* Remane 1986; Lakova 1994; Olóriz et al. 1995; Pop 1996; Reháková & Michalík 1997; Houša et al. 1999; Boughdiri et al. 2006; Andreini et al. 2007; Wimbledon et al. 2011; Michalík & Reháková 2011 and others) (Fig. 9). The lower part of this zone is recognized as coincident with the Tithonian/Berriasian boundary.

Another change is the abrupt decrease in the abundance of *Crassicollaria*. Only a few scarce *Crassicollaria parvula* Remane cross the Jurassic/Cretaceous boundary.

Microfacies show an evident relationship of this subzone with storm deposits. These deposits began in the *Crassicollaria* Zone and are very frequent in the lower part of the *Calpionella* Zone.

The presence of these storm deposits and the considerable amounts of resedimented fossils in the Jurassic/Cretaceous boundary interval may be a response to a sea-level fall during this period, with the consequent influence of the shallower water conditions.

Thus, the Jurassic/Cretaceous boundary is placed within the sample number 23, about 6 meters above the base of the El Americano Member (Fig. 9).

##### *Ferasini Subzone (Samples RSV 38–51)*

Upwards within the El Americano Member, the base of the Ferasini Subzone is characterized by the First Occurrence (FO) of *Remaniella ferasini* Catalano (Fig. 6F,G) (Pop 1994, 1996; Reháková & Michalík 1997) (Fig. 9). This biostratigraphic unit has also been referred to as the *Remaniella* Subzone (Olóriz et al. 1995).

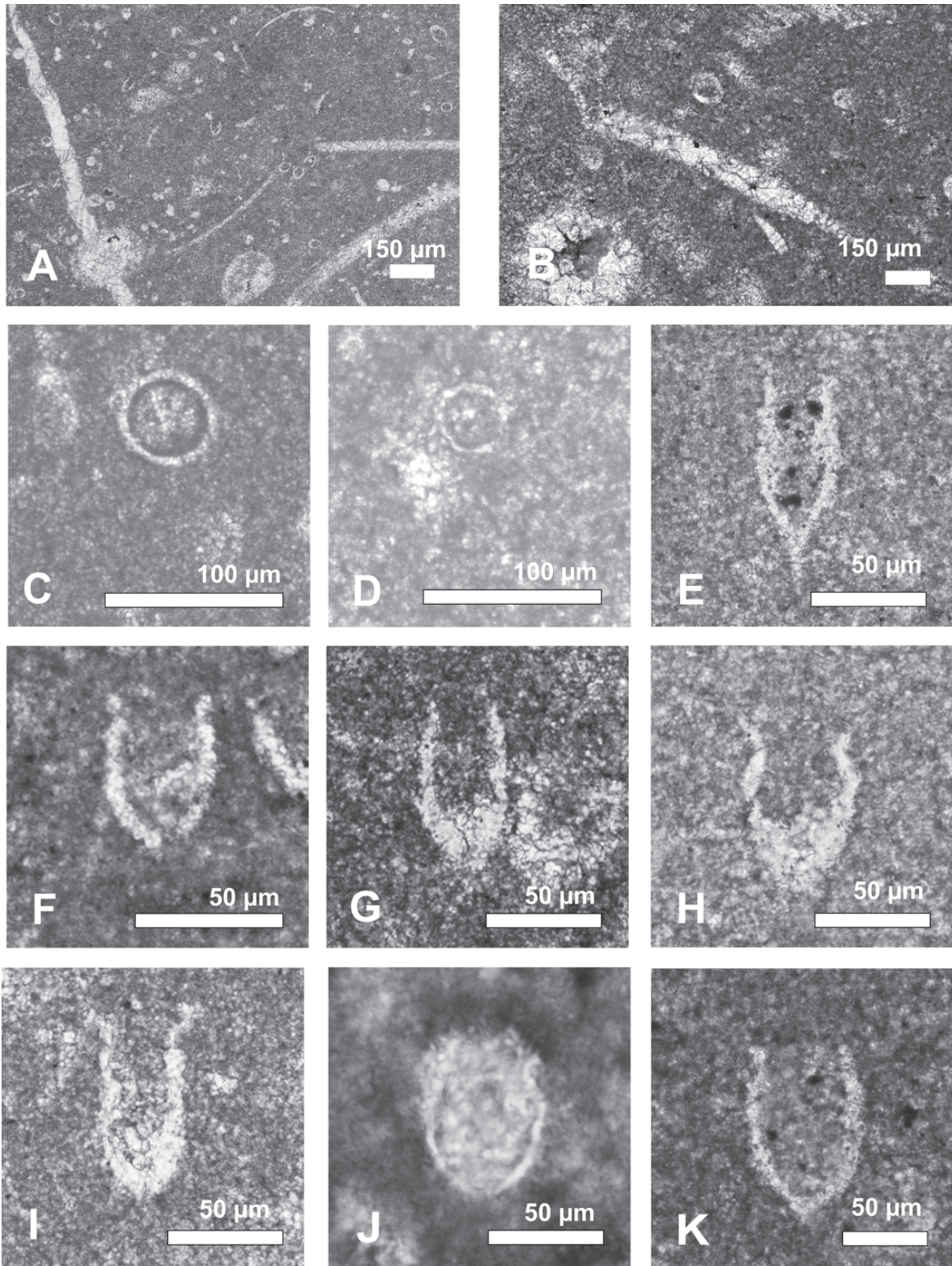
*Remaniella* is scarce and very poorly preserved in the facies studied. Due to the absence of collars only a few specimens were identified. Nonetheless, the shape of the lorica of many specimens resembles the type of the remaniellids. *Calpionella alpina* Lorenz is frequent and dominates the assemblage. *Tintinnopsella carpathica* (Murgeanu & Filipescu) (Fig. 6H) is also frequent; there are also scarce *Crassicollaria parvula*.

The microfacies of this interval are radiolarian and calpionellid mudstones to wackestones. The matrix is microsparitic and dolomitized in some parts and, as a consequence, the collars of the *Remaniella* are persistently damaged (Fig. 6I). Abundant spores of *Globochaete alpina* Lombard were observed (Fig. 6J). Dark organic matter and pyrite are present in all intervals.

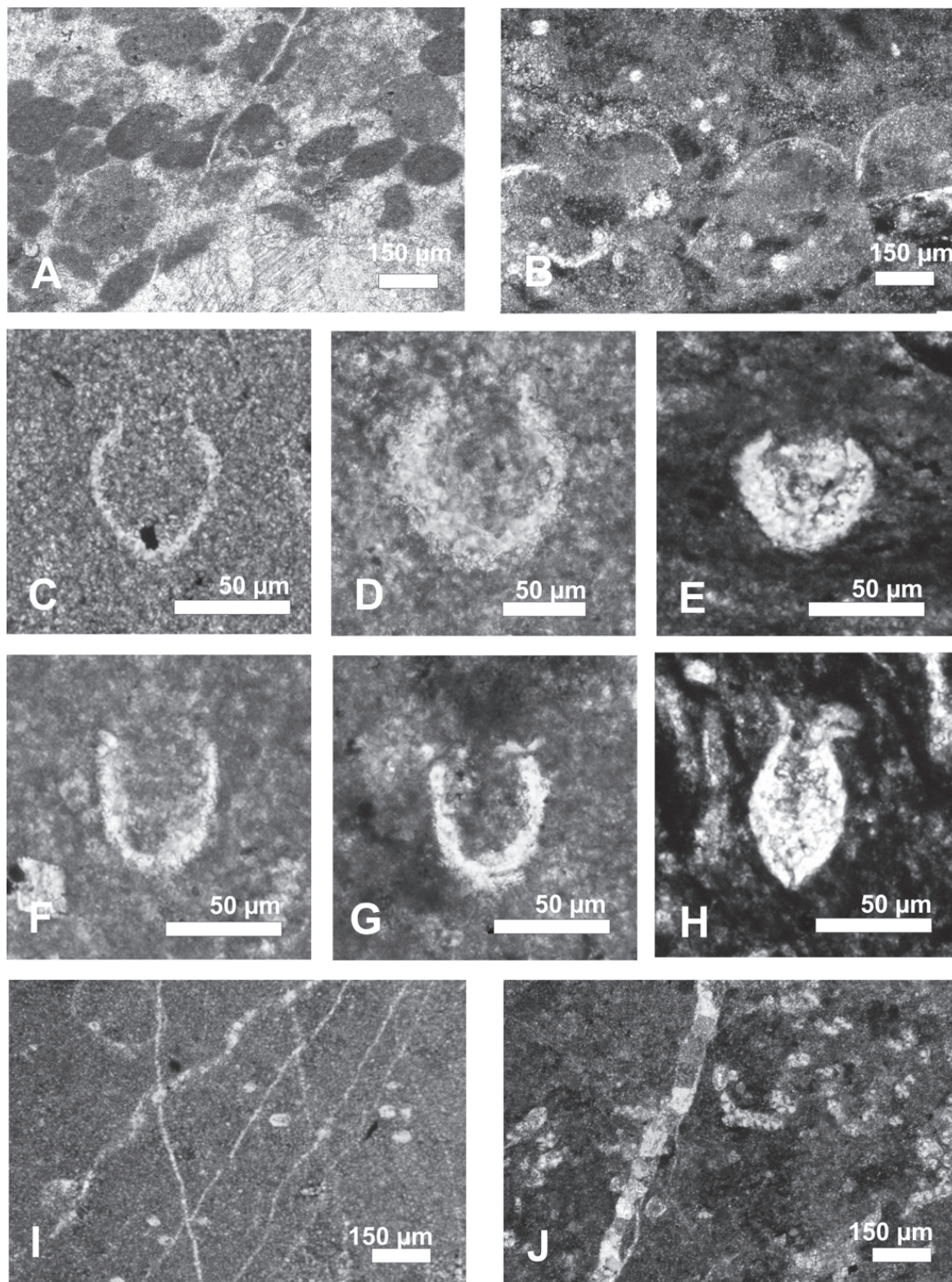
##### *Elliptica Subzone (Samples RSV 52–83)*

The FO of *Calpionella elliptica* Cadish (Fig. 7A) defines the base of the *Elliptica* Subzone (Catalano & Liguori 1971; Reháková & Michalík 1997) and is recognized herein towards the top of the El Americano Member (Fig. 9). *Calpionella alpina* Lorenz still dominates over other species. *Tintinnopsella carpathica* (Murgeanu & Filipescu) is abundant but always subordinated to *Calpionella alpina* Lorenz. *Remaniella* is represented by two species: *Remaniella ferasini* (Catalano) (Fig. 6F,G) and *Remaniella durandelgai* Pop (Fig. 7B). The occurrence of calpionellids joined by the collar (Fig. 7C,D) is very common in this level. This phenomenon was described by Borza (1969) and Colom (1988) and interpreted as the form of calpionellid reproduction.

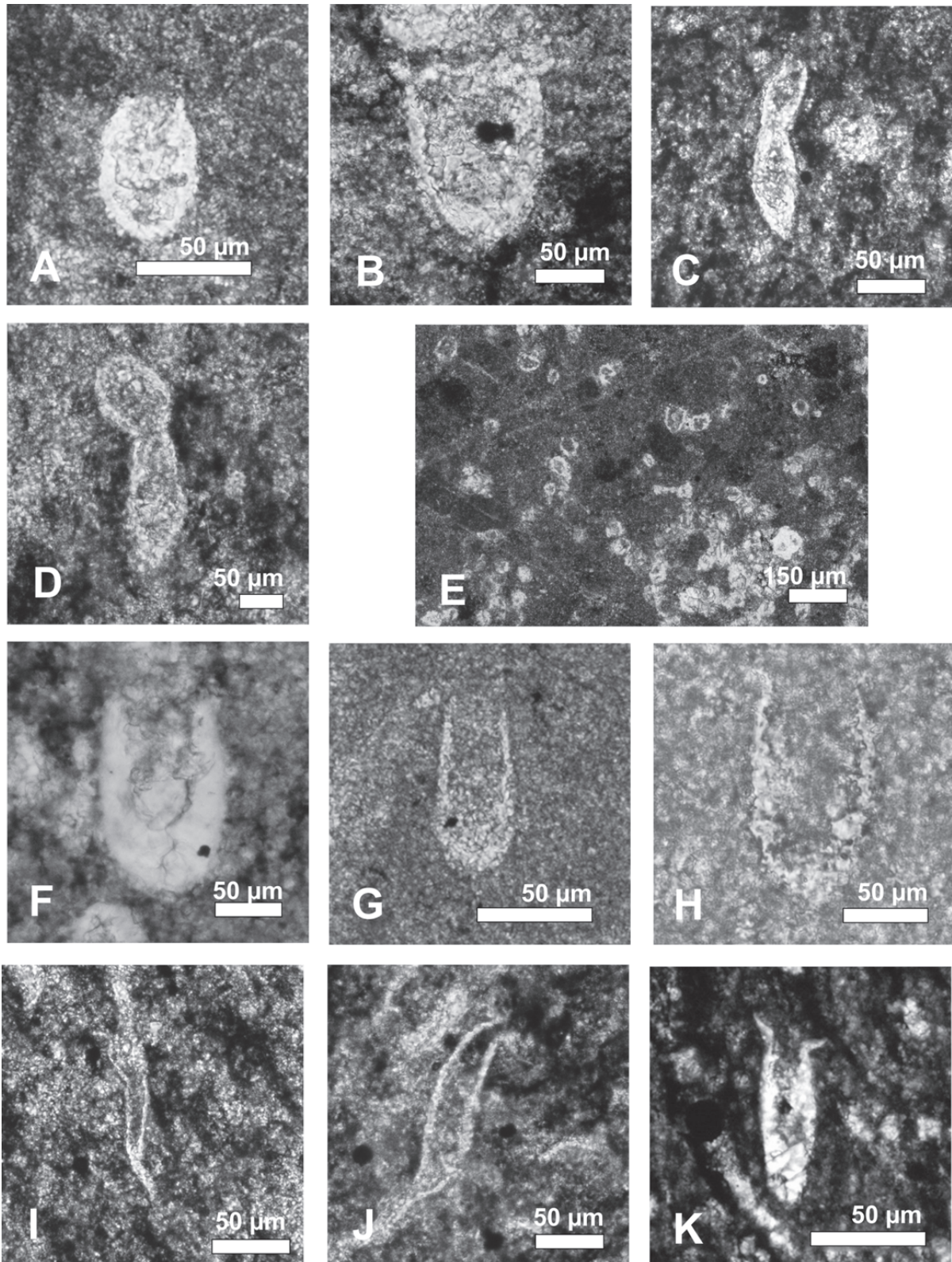
The microfacies of this interval are less variable compared to the preceding. The rocks represent mudstones and wackestones with radiolarians and calpionellids and abundant *Globochaete alpina* Lombard, frequent incursions of resedimented ostracods, pelecypod fragments and abundant bioturbation (Fig. 7E). The rocks commonly contain dark organic matter and the matrix is microsparitic as a rule. This type of preservation makes calpionellids hardly determinable. A reduced number of specimens of *Remaniella* are preserved with collars. The majority of specimens are with damaged or no collar. A frequent recrystallization of the lorica made it impossible to distinguish between different species.



**Fig. 5.** Photomicrographs of microfacies and calpionellids of the *Crassicollaria* Zone. **A, B** — Main components of the *Crassicollaria* Zone. Wackestones–packstones of sponge spicules, radiolarians and calpionellids. Sample RSV-6; **C, D** — *Stomiosphaerina proxima* Rehánek. Sample RSV-10; **E** — *Crassicollaria colomi* Doben. Sample RSV-11; **F** — *Crassicollaria parvula* Remane. Sample RSV-7; **G** — *Crassicollaria massutiniana* (Colom). Sample RSV-7; **H** — *Crassicollaria brevis* Remane. Sample RSV-6; **I** — *Crassicollaria intermedia* Durand-Delga. Sample RSV-7; **J** — *Tintinnopsella remanei* (Borza). Sample RSV-7; **K** — *Tintinnopsella carpathica* (Murgeanu & Filipescu). Sample RSV-15.



**Fig. 6.** Microfacies and calpionellids of the Late Tithonian and Early Berriasian. **A, B** — Storm deposits in the *Crassicollaria* Zone. Picture A shows grainstone of peloids with imbrications. Sample RSV-9; Picture B shows an upper part of the storm deposit with ostracod valves concave down. Sample RSV-9; **C-E** — *Calpionella alpina* Lorenz. Tithonian/Berriasian boundary. Sample RSV-23; **F, G** — *Remaniella ferasini* Catalano. Base of the Ferasini Subzone. Sample RSV-43; **H** — *Tintinnopsella carpathica* (Murgeanu & Filipescu). Sample RSV-46; **I, J** — Characteristic facies of the Ferasini Subzone. **J** — Mudstone-wackestone of calpionellids, radiolarian and sponge spicules. The matrix is microsparitic and the calpionellid collars are preserved only in a few specimens. Sample RSV-51; **K** — Frequent *Globochaete alpina* Lombard in the Ferasini Subzone. Sample RSV-51.



**Fig. 7.** Microfacies and calpionellids of the Elliptica-Oblonga Subzones. **A** — *Calpionella elliptica* Cadish. Sample RSV-62; **B** — *Remaniella duranddelgai* Pop. Sample RSV-72; **C, D** — Calpionellids joined by the collar. Reproduction form according to Borza (1969). Sample RSV-72; **E** — Microfacies of the Elliptica Subzone. Mudstone-wackestone of calpionellids, radiolarians and resedimented material. Sample RSV-72; **F** — *Calpionellopsis simplex* (Colom). Sample RSV-84; **G** — *Calpionellopsis oblonga* (Cadish). Sample RSV-84; **H** — *Tintinnopsella longa* (Colom). Sample RSV-87; **I, J** — Aberrant?, deformed calpionellids in the Oblonga Subzone. Sample RSV-120; **K** — *Tintinnopsella subacuta* (Colom). Sample RSV-120.



**Late Berriasian Calpionellopsis Zone (Samples RSV 84–141)**

An important change in the calpionellid assemblage is marked with the FO of the *Calpionellopsis* which defines the base of the *Calpionellopsis* Zone. In the section studied, this change takes place at the topmost part of the El Americano Member, and the biozone spans into the whole overlying Tumbadero Member (Fig. 9). The FO of the *Calpionellopsis* which is normally represented by *Calpionellopsis simplex* (Colom) (Fig. 7F) in the section studied is concurrent with the appearance of *Calpionellopsis oblonga* (Cadish) (Fig. 7G).

Towards the top of the biozone, *Calpionella alpina* Lorenz and *Calpionella elliptica* Cadish become scarce. On the other hand, *Tintinnopsella carpathica* (Murgeanu & Filipescu) is very common throughout, and the FO of *Tintinnopsella longa* (Colom) (Fig. 7H) is in the middle part of the zone, and the species is always scarce.

It is worth noting the appearance of many aberrant forms within this interval similar to those reported by Reháková (2000b) for the *Calpionellopsis* Zone (Fig. 7I,J). The most diversified calpionellid assemblage is recorded in this interval, and is represented by *Tintinnopsella subacuta* (Colom) (Fig. 7K), *Tintinnopsella longa* Colom (Fig. 7H), *Tintinnopsella carpathica* (Murgeanu & Filipescu) (Fig. 5K), *Amphorellina lanceolata* Colom (Fig. 8A), *Calpionella minuta* Houša (Fig. 8B), *Lorenziella plicata* Le Hégarat & Remane (Fig. 8C), *Remaniella duranddelgai* Pop (Fig. 7B), *Remaniella filipescui* Pop (Fig. 8D) and *Remaniella cadischiana* (Colom) (Fig. 8E).

In the course of the *Calpionellopsis* Zone, an interesting radiolarian and sponges event occurs. The abundance of radiolarians, sponges and organic matter increases considerably. This event affects preservation of the calpionellids. The radiolarian and sponges beds are much silicified, dolomitized and the organic matter is oxidized (Fig. 8F,G). This event may be attributable to upwelling currents.

**Murgeanui Subzone (Sample RSV-141)**

One specimen of *Praecalpionellites murgeanui* Pop (Fig. 8H) was found in the upper part of this interval (sample RSV-141). This index species indicates the presence of the Murgeanui Subzone. No microfacies change is visible in this horizon.

**Early Valanginian Calpionellites Zone, Darderi Subzone (Samples RSV 142–145)**

In an overlying biomicrite limestone (wackestone) containing rare calcified radiolarians and calpionellids, loricas of *Calpionellites darderi* (Colom) (see Fig. 8I) were identified. This index marker characterizes the Early Valanginian Darderi Subzone of the *Calpionellites* Zone.

**Discussion**

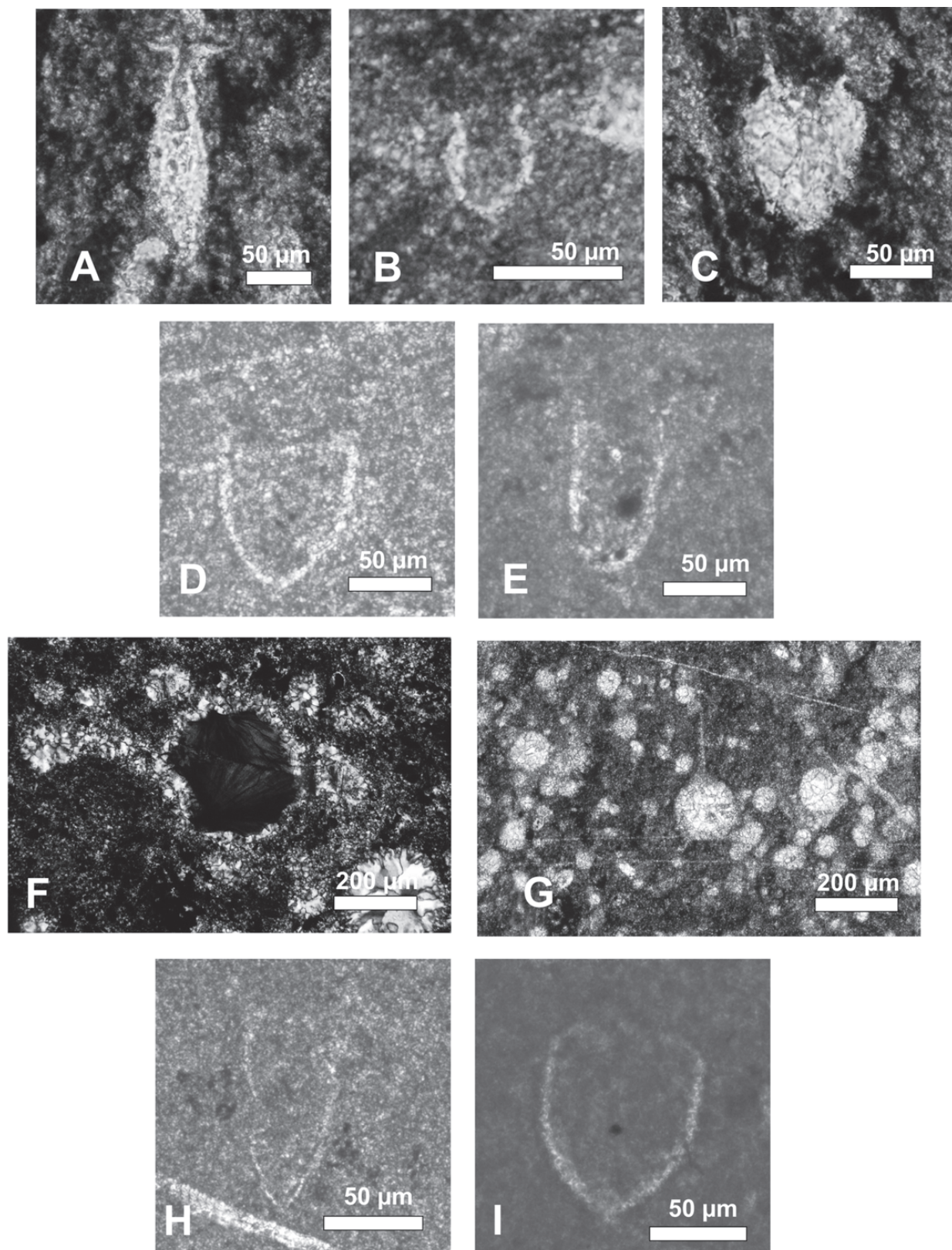
Detailed bed-by-bed sampling in the Rancho San Vicente section of “Sierra de los Órganos” in western Cuba allows

the recognition of a precise calpionellids and facies distribution (Fig. 9).

Lower Tithonian shallow-water carbonated bank San Vicente Member lacks biostratigraphical markers which makes the definition of the stratigraphic range of facies very difficult. Thus, it was dated by superposition and partially by the occurrence of the Early Tithonian Semiradiata Zone underlying the *Chitinoidella*-bearing limestones. The facies of this member are considered in the present work as representing a shallow-water bank without terrigenous influence, but additional work is necessary to define more precisely the dynamics of this carbonated bank. The topmost part of the San Vicente Member is dated as Early Tithonian (Semiradiata Zone). In previous works (Pszczółkowski 1978, 1999), the contact between the San Vicente and the El Americano Members was dated as Kimmeridgian–Tithonian.

The age from Pszczółkowski (1978, 1999) is coincident with Goldhammer & Johnson’s (2001) second order transgression in the Kimmeridgian/Tithonian in the whole Gulf of Mexico province and Proto-Caribbean. Nonetheless, in more detailed work it is possible to find a diachronism in the apparition of the pelagic conditions. This diachronism reveals that the San Vicente carbonated bank prevailed for a time after the initiation of the global sea-level rise. The global sea-level rise started in the Kimmeridgian/Tithonian and the complete drowning of the San Vicente bank occurred in the Upper Tithonian. According to Rosales et al. (1992) an anoxic event took place in the Kimmeridgian/Tithonian in the Gulf of Mexico marked by the formation of facies enriched in organic matter. However, the San Vicente section does not show a clear anoxic facies. In contrast to the assertions by Pszczółkowski & Myczyński (2010), the presence of only juvenile and the scarcity or lack of adult gastropods are interpreted herein as rather due to taphonomic processes, similar to the interpretations by Fernández-López & Meléndez (1995), than as a consequence of low oxygenation levels. The position of the San Vicente section in more oxygenated waters is a reasonable explanation of a longer permanence of the carbonated bank. Nonetheless, we do not have enough evidence to reject the drowning of the San Vicente carbonate bank as a result of sea-level rise and the action of the regional anoxic event on the aforementioned drowning of the carbonate platform.

The pelagic facies represented by the lower part of the El Americano Member are mainly composed by *Saccocoma*-bearing limestones with clear signals of sedimentary and taphonomic condensation (mixture of calpionellid biozones and presence of glauconite). Similar *Saccocoma* facies although Kimmeridgian in age were described by Reháková (2000b). According to Matyszkiewicz (1997) and Keupp & Matyszkiewicz (1997), the saccocomids were very abundant in the late transgressive system tract and probably within the high-stand deposits of the northern Tethys during the Late Oxfordian/Early Kimmeridgian and the latest Kimmeridgian/Early Tithonian. *Saccocoma* is recorded in the United States (Brönnimann 1954), Europe (Pisera & Dzik 1979), Mexico (Aguilera-Franco & Franco-Navarrete 1995), Northern Africa (Matyszkiewicz 1997), Asia (Hess 2002), Cuba (Brodacki 2006) and Argentina (Kietzmann & Palma 2009).



**Fig. 8.** Continuation of the microfacies and calpionellids of the Oblonga, Murgeanui and Darderi Subzones. **A** — *Amphorellina lanceolata* Colom. Sample RSV-120; **B** — *Calpionella minuta* Houša. Sample RSV-89; **C** — *Lorenziella plicata* Le Hégarat & Remane. Sample RSV-90; **D** — *Remaniella filipescui* Pop. Sample RSV-142; **E** — *Remaniella cadischiana* (Colom). Sample RSV-139; **F, G** — Radiolarian event. Picture F displays the facies in polarized light. Sample RSV-106; **H** — *Praecalpionellites murgeanui* Pop. Sample RSV-141; **I** — *Calpionellites darderi* (Colom). Sample RSV-142.

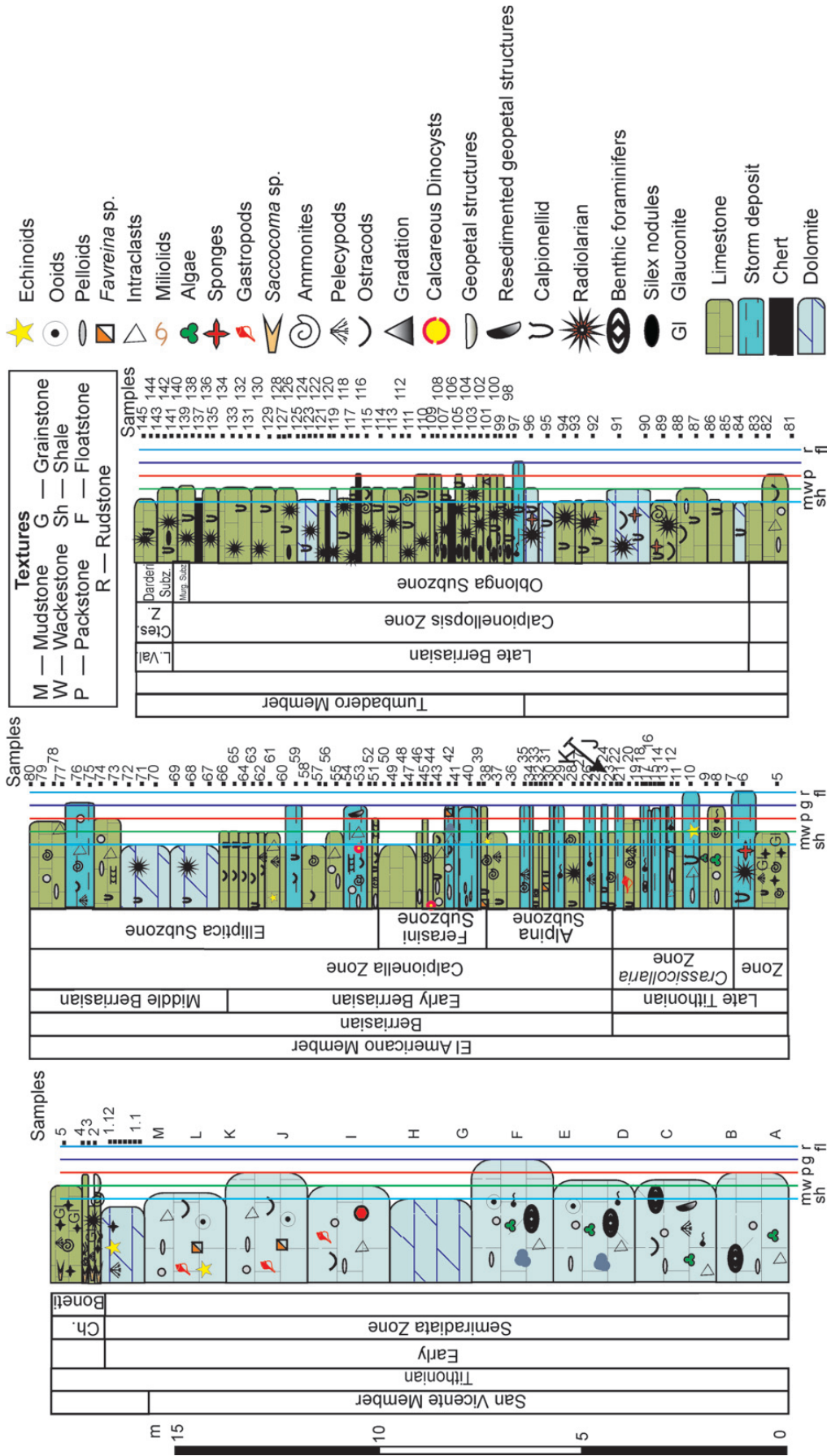


Fig. 9. Stratigraphic column displaying a detailed microfacies distribution and calpionellid biostratigraphy of the San Vicente section.

In all those areas, these facies span from the Kimmeridgian through to the Tithonian.

The recognition of this type of facies in Cuba is important due to its stratigraphical coincidence with coeval strata from Mexico and Argentina. In the three areas (Cuba, Mexico and Argentina), this type of deposits started its record during earliest Late Tithonian and may be the result of a connection between the Tethys and the Pacific Ocean during the sea-level rise. This fact is difficult to discern due to the absence of reports of *Saccocoma* facies in other parts between Mexico and Argentina, which may be due to the scarcity of works on the topic in those areas. It is evident that the sea-level rise identified here within the *Chitinoidea* Zone could be correlated with the same sea-level rise expressed by Reháková (2000b).

The Jurassic/Cretaceous boundary was easily identified because of the dominance of *Calpionella alpina* Lorenz in the assemblage in the bed number RSV-23, about six meters above the base of the El Americano Member. Frequent storm deposits in the top part of the *Crassicollaria* Zone closely related to the Jurassic/Cretaceous boundary could be attributable to a response to a global sea-level drop. This sea-level drop may be correlated with the limit between third order cycles 1.3 and 1.4 in the super cycle LZB1 of the Sea-level curve *sensu* Haq et al. (1988).

It is worth mentioning that previous works (i.e. Pszczółkowski & Myczyński 2010) interpreted the Jurassic-Cretaceous transition as a long-term subsidence that masked the global Tithonian/Berriasian sea-level drop in outcrops of the area. Nonetheless, the abundance of shallow-water fossils (gastropods, pelecypods), reworked materials and abundant storm deposits across this boundary documented in the present research, clearly reflect a sea-level drop after the sea-level rise recorded in the Boneti Subzone and which drowned the San Vicente carbonate bank.

Interesting bioevents occur in the transition between the Elliptica Subzone and the *Calpionellopsis* Zone. This transition should be represented by the FO of the *Calpionellopsis simplex* (Colom), however, the first specimens of the *Calpionellopsis* in the section are identified as *Calpionellopsis oblonga* (Cadish).

The transition through Elliptica-Oblonga Subzones occurred without an apparent sedimentary break in the section and, therefore, it is difficult to associate the absence of the Simplex Subzone to a sedimentary gap. To assess this problem we considered two options. The first refers to the possibility of a very thin Simplex Subzone, and as a consequence, its loss by sampling effect. This explanation is hard to assume due to the intensity of the sampling but there is a possibility to consider a sedimentary condensation. The second assumption is a possible confusion between *Calpionellopsis simplex* and *Calpionellopsis oblonga*, due to the bad preservation. This explanation is hard to assume as well, due to the differences in the morphology of the lorica between the two taxa, even in oblique sections and without preserved collars. Remane (1985) explained that this confusion is only possible in the D2-D3 passage where transitional forms occur. An appropriate explanation of this phenomenon is out of the scope of the present work, and perhaps a regional detailed composite section will be necessary to unravel this biostratigraphic interval in the future.

Another important change in microfacies and fossil assemblage occurs in the Oblonga Subzone. Within this unit, radiolarians and organic matter become very abundant (Fig. 8F,G). The facies of this interval are darker and display frequent siliceous nodules.

The increase of radiolarians and organic matter is attributable in the present work to upwelling currents. This interpretation is supported by the abundance of sponge spicules and by the fact that all siliceous nodules found in the studied section were diagenetic. It is interesting to note that aberrant calpionellids (Fig. 7I,J) are only present within this interval of the radiolarian facies. There may be a relationship between the nitrification associated with the upwelling system and these aberrant calpionellids, but more detailed work is necessary to prove this assertion.

## Conclusion

The high resolution sampling of an outcrop of the Guasasa Formation in the Rancho San Vicente section of the “Sierra de los Órganos” provided new and well-supported data about facies and calpionellid distribution across the Jurassic/Cretaceous boundary in western Cuba. The drowning event of the San Vicente carbonate bank, a major regional paleogeographic element on the facies studied, occurred during the earliest Late Tithonian, Boneti Subzone, and led to deposition of the pelagic facies of the El Americano Member. Thus, the stratigraphic contact between the San Vicente and the El Americano Members, the two lowest units of the Guasasa Formation, is Early/Late Tithonian and not Kimmeridgian/Tithonian as considered in previous works. The sea-level rise associated with this drowning event was probably the cause of the dispersion of *Saccocoma* sp. into different paleogeographic domains, including the Neuquen Basin. The Jurassic/Cretaceous boundary in the studied section is identified at sample number 23, six meters above the contact between the San Vicente and the El Americano Members and not in the topmost part of the latter unit as previously assumed. The facies of this boundary are linked to the global sea-level drop recognized for that age, indicated in the facies of this study by a concomitant shallow-water influence and storm deposits. The top of the stratigraphic section corresponds to the Early Valanginian Darderi Subzone of the *Calpionellites* Zone. Finally, the distribution of calpionellids through the section allows good correlation of the Jurassic/Cretaceous Cuban facies with European sections of the same period. Even though small differences were found between the two areas, they can be attributed to special local sedimentary conditions such as condensation and to bad preservation of some specimens.

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