

# Late Maastrichtian Radiolaria from ODP Leg 165 – Site 999B, Colombian Basin

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## ABSTRACT

This work presents a taxonomic study on the Late Maastrichtian radiolarian fauna from ODP Leg 165, Hole 999B, Colombian Basin. The studied fauna is composed by 24 species, being the family Archaeodictyomitridae Pessagno, 1976 the most abundant and diverse. Original opaline skeletons are replaced by calcium carbonate and precise identifications are possible only for those specimens with sturdy skeletons, what strongly suggests a preservational bias. The studied radiolarian fauna was attributed to the *Amphipyndax tylotus* zone, due to the occurrence of that species. Besides, the fauna described herein presents a low to intermediate latitude paleobiogeographic affinity and falls within the designation of a typical lower bathyal to abyssal one. Finally, the data presented herein are compared to those reported from the closely related ODP Hole 1001B.

## KEY WORDS

Radiolaria,  
Late Maastrichtian,  
Late Cretaceous,  
Paleobiogeography,  
ODP (Ocean Drilling  
Program),  
Colombian Basin.

## RÉSUMÉ

*Radiolaires du Maastrichtien supérieur du site 999B – ODP Leg 165, Bassin colombien.*  
Cette étude présente une approche taxonomique des associations de radiolaires du Maastrichtien supérieur du Site 999B, ODP Leg 165 situé dans le Bassin Colombien. La faune étudiée comprend 24 espèces avec une prédominance (en diversité et abondance) des Archaeodictyomitridae Pessagno, 1976. L'opale d'origine des tests est remplacée par de la calcite, si bien que des identifications spécifiques précises ne sont possibles que pour celles ayant un test robuste. Cette microfaune de radiolaires a été attribuée à la zone à *Amphipyndax tylotus*, en raison de la présence de cette espèce. Cette microfaune présente des affinités paléobiogéographiques de basse à moyenne latitude et est caractéristique de milieux bathyal à abyssal. Les données présentées dans ce travail sont comparées avec celles du site ODP 1001 B.

## MOTS CLÉS

Radiolaires,  
Maastrichtien supérieur,  
Crétacé supérieur,  
Paléobiogéographie,  
ODP (Ocean Drilling  
Program),  
Bassin Colombien.

## INTRODUCTION

The significance of taxonomic studies on Late Cretaceous radiolarian faunas has been emphasized by some authors, improving the paleobiogeographic and stratigraphic knowledge about some taxa (see, for example: Urquhart 1994; Hollis 1997; O'Dogherty *et al.* 2009). Despite this, studies on Maastrichtian radiolarians are relatively rare. Foreman (1968) and Pessagno (1976) studied Maastrichtian radiolarian faunas of California. Ling (1991) and Ling & Lazarus (1990) reported well-preserved Maastrichtian faunas from the Antarctic region; Soloviev *et al.* (2000) reported the occurrence of Campanian-Maastrichtian Radiolaria of Russia; Pessagno (1974) reported Campanian-Maastrichtian radiolarian assemblages recovered from DSDP Site 275, Campbell Plateau, near New Zealand (see age revision of Hollis 1993). Faunal studies documenting the Maastrichtian-Danian transition are reported from New Zealand (Hollis 1993, 1997, 2002; Hollis & Strong 2003; Hollis *et al.* 2003), Japan (Hollis & Kimura 2001) and Equator (Keller *et al.* 1997). In the Caribbean region, Riedel & Sanfilippo (1974) defined in DSDP Site 146, the *Theocapsomma comys* zone, of Maastrichtian age, approximately. Likewise, Aumond *et al.* (2009) described a typical Maastrichtian fauna, dominated by archaeodictyomitrids, in ODP Hole 1001B.

Despite the fact that some of the above mentioned studies pointed out faunal similarities between different regions, interpreted by means of the paleobiogeographical range of the taxa (e.g., Pessagno 1974; Hollis 1993), there are only few works dealing with Upper Cretaceous radiolarian paleobiogeography. Empson-Morin (1984), based on a paleoecological study of Campanian radiolarians from tropical and subtropical oceans, recognized radiolarian assemblages characteristic of certain paleobiogeographic provinces, as well as characteristic of specific paleobathymetries. Likewise, Takahashi's (1999) comparison of Upper Cretaceous (Late Campanian-Early Maastrichtian) radiolarian faunas from different regions of the world, pointed out several useful criteria in the identification of low- to intermediate-latitude assemblages. Vishnevskaya *et al.* (1999), studying the

Shilovka section on the Russian Platform, identified Campanian radiolarian assemblages similar to those described for the boreal western Siberia, but presenting some Tethyan taxa. The identification of radiolarian assemblages of characteristic latitudes has been used in the study of tectonically complex Late Cretaceous areas, enabling even the recognition of plates/terrains motions (e.g., Vishnevskaya & Filatova 1994; Zyabrev 1996).

The main purpose of the present study is the systematic description of a Late Maastrichtian radiolarian fauna from the Colombian Basin as well as the description of its preservational patterns and paleobiogeographic characteristics.

## GEOLOGICAL FRAMEWORK

The present study was carried out in Late Maastrichtian strata from ODP Hole 999B (12°44.597'N, 78°44.418'W; Fig. 1), located in the Colombian Basin. The studied site lies near the Kogi Rise, a basement high that probably represents an oceanic plateau (Sigurdsson *et al.* 1997: 131-230). Seismic and gravity profiles provided evidences for intraplate deformation in the western area of the basin, probably associated with the development of the North Panama Deformed Belt, in the Middle Miocene (Holcombe *et al.* 1990). Three seismic units were identified at the area of the ODP Hole 999B, above the seismic basement, and are correlated with main lithologic changes (see Sigurdsson *et al.* 1997: 131-230).

Sedimentologically, the Late Maastrichtian interval of ODP Hole 999B consists of weakly laminated limestone, with minor amount of interstratified claystone (Fig. 2). It is also characterized by some of the highest values of carbonate content (between 84% and 88%) observed in the site (Sigurdsson *et al.* 1997: 131-230).

The studied interval possesses an accurate biostratigraphic control, based on calcareous nannofossils and planktonic foraminifers (Sigurdsson *et al.* 1997: 152-158). According to nannofossil biostratigraphy, the radiolarian-rich sample (999B/60/2W/70-74 cm) is within the *Nephrolithus frequens* zone (CC26), Late Maastrichtian in age, characterized by the

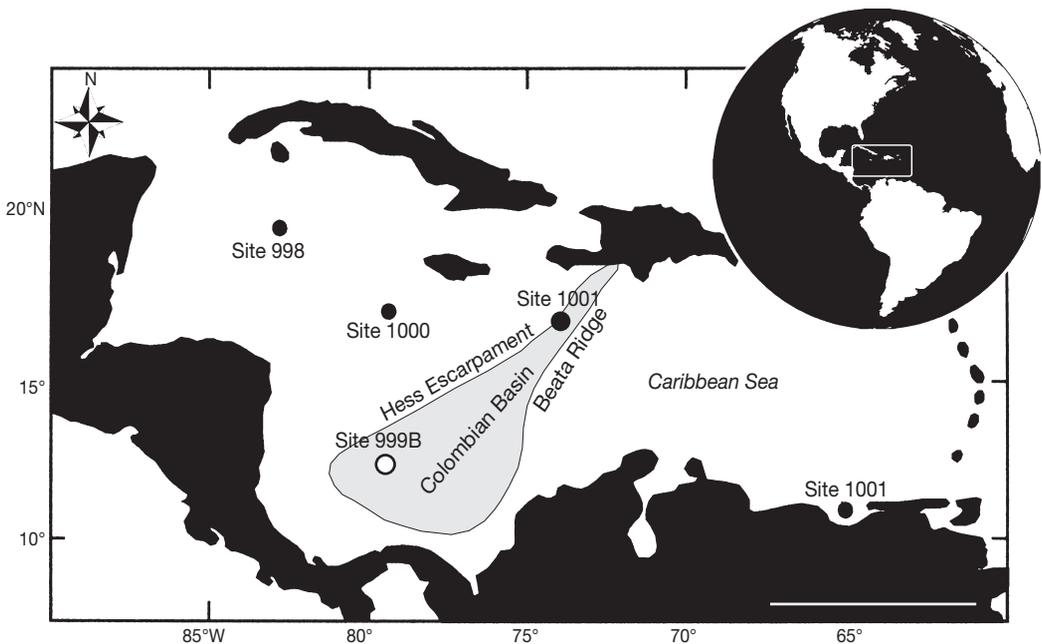


FIG. 1. — Location of ODP Leg 165, Hole 999B, in the Colombian Basin, Caribbean Sea. Basin boundaries obtained from Sinton *et al.* (1998).

occurrence of *Micula murus* (Martini, 1961) and the absence of typical Early Maastrichtian species. Taking into account foraminiferal biostratigraphy, a Late Maastrichtian age is also indicated for the radiolarian-rich sample by the occurrences of *Pseudoguembelina palpebra* Brönnimann & Brown, 1953 and *Planoglobulina multicamerata* (De Klasz, 1953), within the *Abathomphalus mayaroensis* zone or Upper *Gansserina gansseri* zone.

## MATERIAL AND METHODS

The studied interval is composed dominantly by limestone with minor amount of interstratified claystone. Foraminifers are abundant in all 27 studied samples (including those from Danian age), whereas radiolarians occur in only one (999B/60/2W/70-74 cm – greenish limestone). Danian samples were analyzed and defined as barren for radiolarians.

Traditional chemical methods proposed for recovering radiolarians from calcareous rocks, using

about 10% of hydrochloric acid (e.g., Sanfilippo & Riedel 1985; Hollis 1997), were unsuccessful in the preparation of the studied samples, showing progressive dissolution of radiolarian skeletons with time (Fig. 3) and enabling the recovery of only four radiolarian specimens in six grams of bulk sample (in the radiolarian-rich sample). This characteristic suggests that original opaline skeletons are substituted by calcium carbonate and, consequently, chemical preparation with both hydrogen peroxide ( $H_2O_2$ ) and acetic acid ( $CH_3COOH$ ) was performed in the studied samples. At first, the samples were chemically treated according to standard procedures using hydrogen peroxide ( $H_2O_2$ ). Due to the hardness of the studied rocks, the samples were soaked in 29% hydrogen peroxide solution during 72 hours and later washed and fractionated in four meshes (45, 63, 180 and 250  $\mu m$ ). The chemical procedure using acetic acid ( $CH_3COOH$ ) was carried out in accordance to Kariminia (2004), at concentration of 75% with double immersion by eight hours. Although the later procedure was strongly suggested

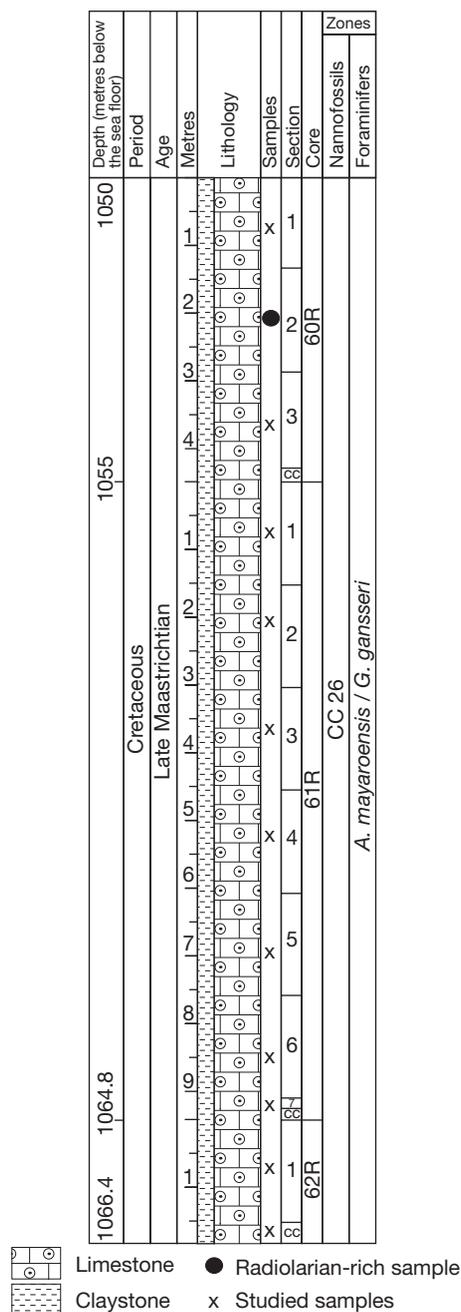


Fig. 2. — Lithostratigraphic profile of ODP Hole 999B, with the location of the radiolarian-rich sample – 999B/60/2W/70–74 cm. Chronostratigraphic and biostratigraphic data from Sigurdsson *et al.* (1997).

for the recovering of radiolarian skeletons replaced by calcium carbonate, the specimens recovered by means of the H<sub>2</sub>O<sub>2</sub> method were better preserved. Radiolarians recovered with both methods (using H<sub>2</sub>O<sub>2</sub> and CH<sub>3</sub>COOH methods) are figured in the taxonomic section of the present study, exhibiting the respective identifications. Finally, specimens were hand-picked under stereo-microscope and representative radiolarians were photographed in Scanning Electron Microscope (SEM) at CENPES/PETROBRAS. In the radiolarian-rich sample, 300 specimens were picked from the residues of both chemical methods, including fragments in order to avoid preservational biases. The radiolarian abundance, preservation index (PI), and nassellarians/spumellarians ratio (N/S) were estimated according to Kiessling (1996). Relative abundances are based on the amount of specimens recovered with the use of the H<sub>2</sub>O<sub>2</sub> method, except for the two specimens only recovered with the CH<sub>3</sub>COOH treatment.

### SYSTEMATIC PALEONTOLOGY

Comprehensive synonymic lists of some species are not repeated here and the reader is conveyed to the original reference. The specimens figured herein will be hold in the collections of Museu de História Geológica do Rio Grande do Sul, Universidade do Vale do Rio dos Sinos (UNISINOS), Brazil, under the curatorial numbers ULVG-7319 to ULVG-7341 and ULVG-8312.

Order NASSELLARIA Ehrenberg, 1875  
 Family ARCHAODICTYOMITRIDAE Pessagno, 1976  
 Genus *Archaeodictyomitra* Pessagno, 1976

*Archaeodictyomitra* cf. *A. squinaboli*  
 Pessagno, 1976  
 (Fig. 4A)

FIGURED SPECIMEN. — ULVG-7319.

MATERIAL. — One specimen (recovered with the hydrogen peroxide method).

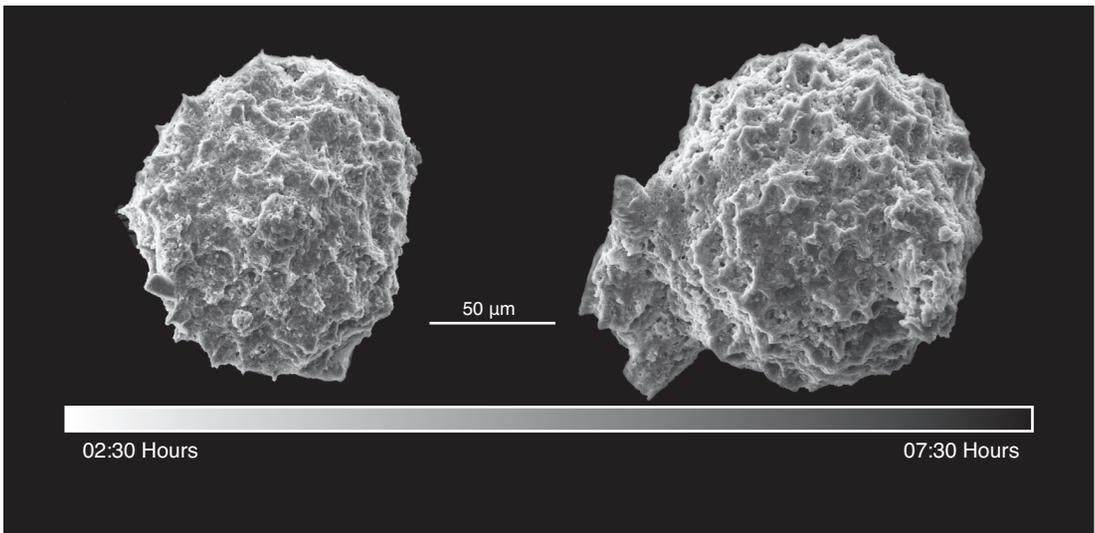


FIG. 3. — Differential dissolution patterns for two specimens of *Praeconocaryomma californiense* Pessagno, 1976 soaked for 02:30 and 07:30 hours in a solution containing hydrochloric acid (HCl), at concentration of 10%. There is no evidence of the thin circular spines, characteristic of species, on the specimen exposed for more time to HCl.

#### REMARKS

The specimen figured herein presents more widely spaced costae in relation to the original description of Pessagno (1976), consisting of nine costae in lateral view. Pessagno (1976) described approximately 11 costae in lateral view, although, even in the specimens figured by him, this characteristic is highly variable.

The poor preservation of the studied specimen did not allow the identification of the relict pores described by Pessagno (1976).

*Archaeodictyomitra* cf. *A. lamellicostata*  
(Foreman, 1968)  
(Fig. 4B)

FIGURED SPECIMEN. — ULVG-7320.

MATERIAL. — Two specimens (recovered with the hydrogen peroxide method).

#### REMARKS

Although the number of costae is apparently the same, this species is a little smaller than the holotype of *A. lamellicostata*.

*Archaeodictyomitra?* sp. 1  
(Fig. 4C)

FIGURED SPECIMEN. — ULVG-7321.

MATERIAL. — One specimen (recovered with the hydrogen peroxide method); one specimen (recovered with the acetic acid method).

#### DESCRIPTION

Test somewhat spindle shaped; non-lobulate, with poor-developed strictures and costate throughout. Cephalis probably imperforate and rounded apically. One row of pores between adjacent costae.

#### REMARKS

The poor preservation makes difficult a more precise taxonomic identification.

*Archaeodictyomitra?* sp. 2 (Fig. 4D)

FIGURED SPECIMEN. — ULVG-7323.

MATERIAL. — 28 specimens (recovered with the hydrogen peroxide method); 28 specimens (recovered with the acetic acid method).

#### DESCRIPTION

Test conical proximally and cylindrical distally; non-lobulated, with poor-developed strictures and costate throughout. Costae converging in the cephalic area. Cephalis probably imperforated and sharply pointed apically. One row of pores (probably relicts) between adjacent costae. Distal margin ragged, with poor-developed costal projections.

#### REMARKS

Although O'Dogherty (1994) suggested a broader definition of the genus *Dictyomitra* Zittel, 1876, we follow Pessagno's (1976) criteria and tentatively attribute this species to *Archaeodictyomitra* (i.e. non-lobulated outline and continuous costae). The poor preservation of all specimens does not enable the recognition of primary pores and prevents the specific identification of the specimens.

Genus *Dictyomitra* Zittel, 1876

*Dictyomitra* sp. 1  
(Fig. 4E)

FIGURED SPECIMEN. — ULVG-7322.

MATERIAL. — One specimen (recovered with the hydrogen peroxide method); seven specimens (recovered with the acetic acid method).

#### DESCRIPTION

Test conical proximally and becoming somewhat cylindrical distally; lobulate and costate throughout (about 11 costae in lateral view). Cephalis sharply pointed apically, with costae converging in the cephalic area. Post-cephalic segments somewhat cylindrical. Distal margin ragged, with poor-developed costal projections.

#### REMARKS

The poor preservation of the specimens does not assure the specific identification.

*Dictyomitra* sp. 2  
(Fig. 4F)

FIGURED SPECIMEN. — ULVG-7324.

MATERIAL. — 23 specimens (recovered with the hydrogen peroxide method); two specimens (recovered with the acetic acid method).

#### DESCRIPTION

Multi-segmented form (six to eleven segments), with test elongated and conical shape. Well-developed and vertically aligned costae obscured on cephalis. Cephalis slightly acute apically. Between adjacent costae, a single parallel row of aligned sub-circular pores or sub-circular depressions is present. Deep and well-developed constrictions occur at joints between segments, formed possibly by one or two transverse pore rows, and are followed by the costae outline. Costae are normally obscured at strictures. One transverse depressed row is present on the central part of each abdominal and post-abdominal segment. Lateral outline of the test strongly lobulated at segmental division levels. Chambers gradually increasing in length and width distally. Distal margin ragged, having, or not, small costal projections.

#### REMARKS

*Dictyomitra* sp. 2 differs from both *D. multicosata* Zittel, 1876 and *D. formosa* Squinabol, 1904 by the transverse depression in the central part of each abdominal and post-abdominal segment. Likewise, *D. formosa* normally presents the first post-abdominal segment inflated, producing a kind of ledge neck, and does not have constrictions at the apical (proximal) region. *Dictyomitra multicosata* has slighter constrictions. This species presents some similarities to *Dictyomitra* sp. 2, recorded by Aumond *et al.* (2009) from Maastrichtian strata of ODP Hole 1001B, but it has segments more angular in outline.

Genus *Mita* Pessagno, 1977

*Mita regina?* (Campbell & Clark, 1944)  
(Fig. 4G)

FIGURED SPECIMEN. — ULVG-8312.

MATERIAL. — One specimen (recovered with the acetic acid method).

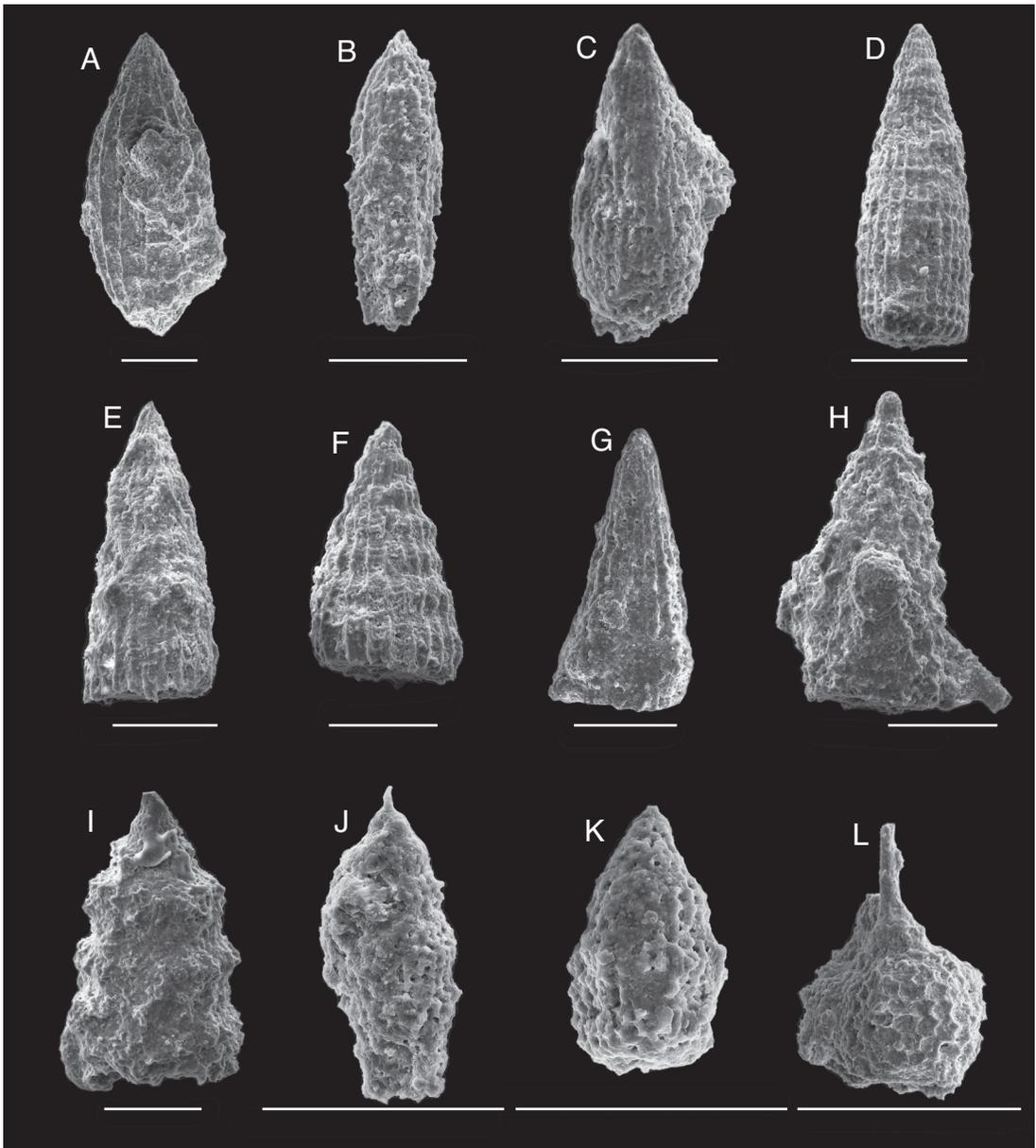


FIG. 4. — SEM images of Radiolaria recovered from the sample 999B/60/2W/70-74 cm: **A**, *Archaeodictyomitra* cf. *A. squinaboli* Pes-sagno, 1976 (H<sub>2</sub>O<sub>2</sub> method); **B**, *Archaeodictyomitra* cf. *A. lamellicostata* (Foreman, 1968) (H<sub>2</sub>O<sub>2</sub> method); **C**, *Archaeodictyomitra*? sp. 1 (H<sub>2</sub>O<sub>2</sub> method); **D**, *Archaeodictyomitra*? sp. 2 (H<sub>2</sub>O<sub>2</sub> method); **E**, *Dictyomitra* sp. 1 (H<sub>2</sub>O<sub>2</sub> method); **F**, *Dictyomitra* sp. 2 (H<sub>2</sub>O<sub>2</sub> method); **G**, *Mita regina*? (Campbell & Clark, 1944) (CH<sub>3</sub>COOH method); **H**, *Amphipyndax tyloisus* Foreman, 1978 (H<sub>2</sub>O<sub>2</sub> method); **I**, *Stichomitra asymbatos* Foreman, 1968 (H<sub>2</sub>O<sub>2</sub> method); **J**, *Stichomitra*? sp. 1 (H<sub>2</sub>O<sub>2</sub> method); **K**, *Stichomitra*? sp. 2 (H<sub>2</sub>O<sub>2</sub> method); **L**, *Rhopalosyringium magnificentum* Campbell & Clark, 1944 (H<sub>2</sub>O<sub>2</sub> method). The chemical compound after each species indicates the chemical method applied in the recovery of each figured specimen. Scale bars: 100 µm.

REMARKS

Preservation obscures some characteristics attributed to the species in its original description.

Family AMPHIPYNDACIDAE Riedel, 1967

Genus *Amphipyndax* Foreman, 1966

*Amphipyndax tylotus* Foreman, 1978  
(Fig. 4H)

*Amphipyndax tylotus* Foreman, 1978: 745, pl. 4, figs 1, 2. — Sanfilippo & Riedel 1985: 598, fig. 7-2a, b.

FIGURED SPECIMEN. — ULVG-7325.

MATERIAL. — 12 specimens (recovered with the hydrogen peroxide method); nine specimens (recovered with the acetic acid method).

OCCURRENCE. — Upper Campanian to Maastrichtian of central Pacific, and western and eastern central Atlantic (Sanfilippo & Riedel 1985); Late Campanian to Early Maastrichtian of Japan (Hollis & Kimura 2001).

REMARKS

*Amphipyndax tylotus* differs from *A. pseudoconulus* (Pessagno, 1963) by the randomly distributed nodes on the skeleton surface instead of restricted to the segmental divisions. For the revised synonymy of the species see Hollis & Kimura (2001).

Family EUCYRTIDIIDAE Ehreberg, 1847

Genus *Stichomitra* Cayeux, 1897

*Stichomitra asymbatos* Foreman, 1968  
(Fig. 4I)

*Stichomitra asymbatos* Foreman, 1968: 73, pl. 8, fig. 10a-c.

*Stichomitra grandis* – Hollis 1997: 78, pl. 19, figs 1-4 and synonymy therein.

*Stichomitra asymbatos* – Aumond *et al.* 2009: 200, fig. 3I, J.

FIGURED SPECIMEN. — ULVG-7326.

MATERIAL. — Eight specimens (recovered with the hydrogen peroxide method); three specimens (recovered with the acetic acid method).

OCCURRENCE. — Upper Maastrichtian of California (Foreman 1968); Late Campanian-Maastrichtian to Early Paleocene of New Zealand (Hollis 1997); Maastrichtian of Caribbean Sea (Aumond *et al.* 2009).

*Stichomitra?* sp. 1  
(Fig. 4J)

FIGURED SPECIMEN. — ULVG-7327.

MATERIAL. — Four specimens (recovered with the hydrogen peroxide method); two specimens (recovered with the acetic acid method).

DESCRIPTION

Multi-segmented Nassellaria (with probably six segments), spindle-shaped in outline. The poreless cephalis bears a small and curved apical horn. Post-cephalic segments increase regularly in width and height until a median segment; strictures between segments well-developed. Thorax, abdomen and post-abdominal segments possess circular pores, apparently, quincuncially arranged. Distal segments inverted conical in shape.

REMARKS

Besides its similarity to *Stichomitra carnegiense* (Campbell & Clark, 1944), the poor preservation of the recovered specimens does not enable the identification of the key characteristics in the apical horn, and in the upper segments. In disagreement to the description of *S. carnegiense*, the described species also bears spindle-shaped outline.

*Stichomitra?* sp. 2  
(Fig. 4K)

FIGURED SPECIMEN. — ULVG-7328.

MATERIAL. — 18 specimens (recovered with the hydrogen peroxide method); 15 specimens (recovered with the acetic acid method).

DESCRIPTION

Small Nassellaria with poorly developed segmental divisions. Pores of the test present well-developed polygonal pore-frames. The species possesses an apical horn (broken in the figured specimen).

## REMARKS

The poor development of segmental divisions in all recovered specimens does not enable their precise visualization and, consequently, makes difficult a more precise statement.

Family CANNOBOTRYIDAE Haeckel, 1881  
Genus *Rhopalosyringium*  
Campbell & Clark, 1944

*Rhopalosyringium magnificum*  
Campbell & Clark, 1944 (Fig. 4L)

*Rhopalosyringium magnificum* Campbell & Clark, 1944: 30, pl. 7, figs 16, 17. — Empson-Morin 1981: 265, pl. 8, fig. 1a-d and synonymy therein.

FIGURED SPECIMEN. — ULVG-7329.

MATERIAL. — 17 specimens (recovered with the hydrogen peroxide method); five specimens (recovered with the acetic acid method).

OCCURRENCE. — Maastrichtian of California (Campbell & Clark 1944); Campanian of DSDP Leg 32, Site 313, Mid-Pacific Mountain (Empson-Morin 1981).

*Rhopalosyringium kleinum* Empson-Morin, 1981  
(Fig. 5A)

*Rhopalosyringium kleinum* Empson-Morin, 1981: 265, pl. 8, figs 2, 3 and synonymy therein.

FIGURED SPECIMEN. — ULVG-7330.

MATERIAL. — Two specimens (recovered with the hydrogen peroxide method); 11 specimens (recovered with the acetic acid method).

OCCURRENCE. — Campanian of DSDP Leg 32, Site 313, Mid-Pacific Mountain (Empson-Morin 1981).

Genus *Botryometra* Petrushevskaya, 1975

*Botryometra heros* (Campbell & Clark, 1944)  
(Fig. 5B)

*Lithomelissa* (*Micromelissa*) *heros* Campbell & Clark, 1944: 25, pl. 7, fig. 23.

?*Lithomelissa heros* – Foreman 1968: 25, pl. 3, fig. 5a, b.

*Botryometra heros* – Moix *et al.* 2009: fig. 4K.

FIGURED SPECIMEN. — ULVG-7331.

MATERIAL. — Five specimens (recovered with the hydrogen peroxide method).

OCCURRENCE. — Maastrichtian of California (Campbell & Clark 1944; Foreman 1968); Campanian of Turkey (Moix *et al.* 2009).

## REMARKS

This species was not assigned to ?*Lithomelissa hoplites* Foreman, 1968 due the absence of ridges extending from the apical horn on to the cephalis, as well as the absence of upward-directed spiny projections on these ridges. Likewise, ?*L. hoplites* possesses a poreless cephalis and dorsal and primary wings extended from the three edges of the triangular thorax (Foreman 1968).

Family WILLIRIEDELLIDAE  
Dumitrica, 1970  
Genus *Cryptamphorella*  
Dumitrica, 1970

*Cryptamphorella* sp. (Fig. 5C)

FIGURED SPECIMEN. — ULVG-7332.

MATERIAL. — Eight specimens (recovered with the hydrogen peroxide method); 59 specimens (recovered with the acetic acid method).

## DESCRIPTION

Three-segmented form with poreless cephalis, perforated thorax and large inflated abdomen. Thorax partially hidden into the abdomen. Pores of the thorax and abdomen are sub-circular and arranged in polygonal pore-frames.

## REMARKS

This species differs from *Cryptamphorella conara* (Foreman, 1968) in having apparently primary pores on the thorax, and by its less depressed thorax into the abdominal cavity.

Family CARPOCANIIDAE

Haeckel, 1881 (emend. Riedel 1967)

Genus *Theocapsomma*

Haeckel, 1887 (emend. Foreman 1968)

*Theocapsomma* sp.

(Fig. 5D)

FIGURED SPECIMEN. — ULVG-7333.

MATERIAL. — One specimen (recovered with the acetic acid method).

DESCRIPTION

Test of three segments. Cephalis completely encased in thorax, generating a dome shaped cephalo-thoracic portion, and bearing a small apical spine. Thorax hemispherical with subcircular pores enclosed in polygonal pore frames, with small nodes protruding from the corners. Lumbar stricture moderately defined externally. Thorax subcylindrical with subcircular pores longitudinally arranged. Distal margin probably ragged.

REMARKS

The absence of a vertical tube does not enable a direct comparison to *Theocampe daseia* Foreman, 1968 and *T. bassilis* Foreman, 1968.

Order SPUMELLARIA Ehrenberg, 1875

Family CONOCARYOMMIDAE

Lipman, 1969 (emend. De Wever *et al.* 2001)

Genus *Praeconocaryomma* Pessagno, 1976

*Praeconocaryomma californiense*

Pessagno, 1976

(Fig. 5E)

*Praeconocaryomma californiense* Pessagno, 1976: 41, pl. 7, figs 1-8; 1977: 942, pl. 3, figs 3-6. — Packer & Hart 2005: 144, fig. 7j, k. — Vishnevskaya & Alekseev 2008: 1368, fig. 2f. — Aumond *et al.* 2009: 201, fig. 3W.

FIGURED SPECIMEN. — ULVG-7334.

MATERIAL. — 18 specimens (recovered with the hydrogen peroxide method); five specimens (recovered with the acetic acid method).

OCCURRENCE. — Coniacian of Great Valley Sequence, California (Pessagno 1976, 1977); Coniacian-Santonian of Bornholm, Denmark (Packer & Hart 2005); Santonian-Campanian of Kara Crater, Russia (Vishnevskaya & Alekseev 2008); Maastrichtian of Caribbean Sea (Aumond *et al.* 2009).

Family PSEUDOALOPHACIDAE Riedel, 1967

(emend. De Wever *et al.* 2001)

Genus *Alievium* Pessagno, 1972

*Alievium?* sp.

(Fig. 5F)

FIGURED SPECIMEN. — ULVG-7335.

MATERIAL. — Six specimens (recovered with the hydrogen peroxide method).

DESCRIPTION

Test without tholi and sub-triangular in outline; with meshwork comprised of pores and nodes, as commonly presented by the family.

REMARKS

The poor preservation of all recovered specimens does not enable a more precise identification.

Family ANGULOBACCHIIDAE

Baumgartner, 1980

(emend. De Wever *et al.* 2001)

Genus *Paronaella* Pessagno, 1971

*Paronaella?* sp.

(Fig. 5G)

FIGURED SPECIMEN. — ULVG-7336.

MATERIAL. — One specimen (recovered with the hydrogen peroxide method).

DESCRIPTION

Three-rayed test without brachchiopyle. Rays possibly elliptical in cross-section. Test rough without lateral or central spines. Rays tending to be slender distally and keep practically the same inter-rays angle. Central area slightly elevated.

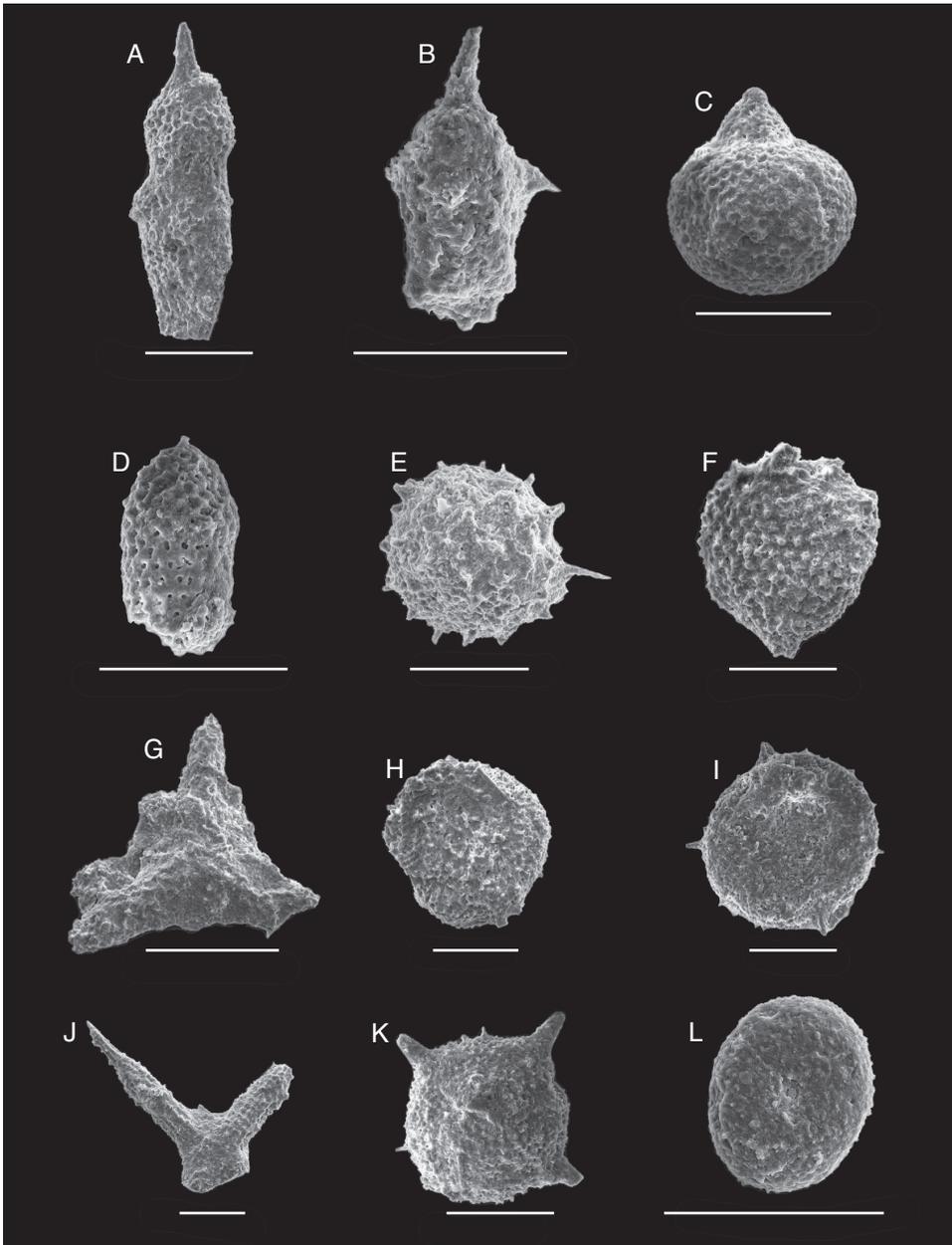


FIG. 5. — SEM images of Radiolaria recovered from sample 999B/60/2W/70-74 cm: **A**, *Rhopalosyringium kleinum* Empson-Morin, 1981 ( $H_2O_2$  method); **B**, *Botryometra heros* (Campbell & Clark, 1944) ( $H_2O_2$  method); **C**, *Cryptamphorella* sp. ( $H_2O_2$  method); **D**, *Theocapsomma* sp. (Empson-Morin, 1981) ( $CH_3COOH$  method); **E**, *Praeconocaryomma californiense* Pessagno, 1976 ( $H_2O_2$  method); **F**, *Alievium?* sp. ( $H_2O_2$  method); **G**, *Paronaella?* sp. ( $H_2O_2$  method); **H**, *Orbiculiforma* sp. 1 ( $H_2O_2$  method); **I**, *Orbiculiforma* sp. 2 ( $CH_3COOH$  method); **J**, *Crucella* sp. ( $H_2O_2$  method); **K**, *Tholodiscus* sp. ( $H_2O_2$  method); **L**, *Spumellaria* gen. et sp. indet. ( $H_2O_2$  method). The chemical compound after each species indicates the chemical method applied in the recovery of each figured specimen. Scale bars: 100  $\mu m$ .

Family HAGIASTRIDAE Riedel, 1971  
Genus *Orbiculiforma* Pessagno, 1973

*Orbiculiforma* sp. 1 (Fig. 5H)

FIGURED SPECIMEN. — ULVG-7337.

MATERIAL. — Two specimens (recovered with the hydrogen peroxide method).

DESCRIPTION

Test heart-shaped, with shallow central cavity. It presents a spongy meshwork, as well as, possible broken spines.

REMARKS

The outline of the specimens presents some similarities to *Orbiculiforma persenex* Pessagno, 1976, however, the poor preservation, as well as the presence of possible broken spines, does not enable a more precise taxonomic identification.

*Orbiculiforma* sp. 2 (Fig. 5I)

FIGURED SPECIMEN. — ULVG-7338.

MATERIAL. — Three specimens (recovered with the hydrogen peroxide method); two specimens (recovered with the acetic acid method).

DESCRIPTION

Test is circular in outline, with or without peripheral spines. The center of test is shallowly depressed (central cavity); the central cavity is flanked by a poor-developed rim. There are small circular pores, irregularly distributed over the test. The periphery of the external rim presents a rough aspect.

REMARKS

There is a small nassellarian attached to the figured specimen.

Genus *Crucella* Pessagno, 1971

*Crucella* sp.  
(Fig. 5J)

FIGURED SPECIMEN. — ULVG-7339.

MATERIAL. — Three specimens (recovered with the hydrogen peroxide method); two specimens (recovered with the acetic acid method).

DESCRIPTION

Four-rayed hagiastrid, without brachiopyle. Rays are equal in length, sharply pointed distally, with tri(?)-bladed spines at extremities. Rays are sub-circular to elliptical in cross-section. Central area slightly elevated. Rays present pores composed of tetragonal pore-frames, linearly aligned.

REMARKS

All the recovered specimens present broken spines at extremities.

Family SPONGODISCIDAE Haeckel, 1862

Genus *Tholodiscus*

Petrushevskaya & Koslova, 1972

*Tholodiscus* sp.  
(Fig. 5K)

FIGURED SPECIMEN. — ULVG-7340.

MATERIAL. — Five specimens (recovered with the hydrogen peroxide method); four specimens (recovered with the acetic acid method).

DESCRIPTION

Discoidal test with rounded quadrangular outline and spongy meshwork. Four radial spines extend from the quadrant boundaries. Central area of each quadrant with secondary spines.

REMARKS

This species differs from the species assigned to the genus *Orbiculiforma* Pessagno, 1973 by the four radial spines at the quadrant boundaries.

*Spumellaria* incertae sedis

*Spumellaria* gen. et sp. *indet.*  
(Fig. 5L)

FIGURED SPECIMEN. — ULVG-7341.

**MATERIAL.** — Four specimens (recovered with the hydrogen peroxide method); two specimens (recovered with the acetic acid method).

#### DESCRIPTION

Test ellipsoidal, possibly composed of a spongy meshwork and without radial spines. Pores are of sub-circular outline and the skeleton surface is smooth.

#### REMARKS

The absence of diagnostic features does not enable a precise identification.

### RESULTS AND DISCUSSIONS

Radiolarians occur in only one Late Maastrichtian sample (999B/60/2W/70-74 cm), in which the estimated abundance is of about 200 rad/g (radiolarians per gram) – using the H<sub>2</sub>O<sub>2</sub> chemical method, PI (preservation index) = 4 to 5 (average to fair) and N/S (Nassellaria/Spumellaria ratio) = 2.43 (indexes estimated according to Kiessling [1996]). About 38% of the specimens were fragmented, but counted in order to avoid biases.

The 24 species that compose the studied fauna were assigned to the families Archaeodictyomitridae, Amphipyndacidae, Eucyrtidiidae, Cannobotryidae, Williriedellidae, Carpocaniidae, Conocaryomimidae, Pseudoaulophacidae, Angulobracchiidae, Hagiastriidae and Spongodiscidae. The family Archaeodictyomitridae is the dominant taxon, presenting the highest richness (seven species) and abundance (32.7% of the specimens). Table 1 presents the relative abundances of all species described in the studied assemblage, being *Archaeodictyomitra?* sp. 2, *Dictyomitra* sp. 2, *Amphipyndax tylotus*, *Rhopalosyringium magnificum* and *Praeconocaryomma californianaensis* the most abundant.

Despite the scarcity of radiolarians in the Upper Cretaceous of ODP Hole 999B, a feature that is common in Upper Cretaceous stratigraphic successions elsewhere (e.g., De Wever & Baudin 1996), the present study revealed some interesting results. The taxonomic study, for instance, suggests longer stratigraphical ranges for some taxa

(*Rhopalosyringium kleinum* and *Praeconocaryomma californianaensis*), in accordance to data previously reported by Aumond *et al.* (2009). In accordance to the biostratigraphic data previously presented for ODP Hole 999B (see geological framework section), the occurrence of *Amphipyndax tylotus* in the studied assemblage permits the identification of the *Amphipyndax tylotus* zone, Upper Campanian to Maastrichtian in age (see Sanfilippo & Riedel 1985). In order to improve the analysis presented herein, the material described by Aumond *et al.* (2009) was revised and specimens securely assignable to *Amphipyndax tylotus* identified. Besides, the Aumond's *et al.* (2009) specimen identified as *Amphipyndax pseudoconulus* (Fig. 3N) is probably a misidentification. The tendency of an irregular arrangement of the external ridges seems to be more suitable to *Amphipyndax tylotus* diagnosis or, at least, corresponds to a transitional form between both species. Concluding, besides their geographic proximity, both assemblages herein discussed (described herein and those of Aumond *et al.* 2009) can be assigned to the same radiolarian zone.

Despite the differences between the assemblage described herein and those Maastrichtian ones of Aumond *et al.* (2009), *Amphipyndax tylotus*, *Stichomitra asymbatos* and *Praeconocaryomma californianaensis* are shared by both sites. Moreover, there are affinities to the Maastrichtian faunas from the California region registered by both Pessagno (1976) and Foreman (1968), as well as to the Upper Cretaceous fauna reported by Campbell & Clark (1944). These affinities are based on the occurrences of *Archaeodictyomitra* cf. *A. lamellicostata*, *Stichomitra asymbatos*, *Botryometra heros* and *Praeconocaryomma californianaensis*. On the other hand, similarities between the fauna from the ODP Hole 999B and those from high latitudes (e.g., Pessagno 1974) are not so evident. It only occurs at generic level and well-known cosmopolitan species, overstating any paleobiogeographic discussion.

The comparison of the present results to the geographically and stratigraphically related ones by Aumond *et al.* (2009), reveals the poor preservation and lower richness of the studied assemblage. Besides this, the studied specimens have

TABLE 1. — Relative abundance of each species described in the studied assemblage.

Species	Relative abundances (%)
<i>Archaeodictyomitra</i> cf. <i>A. squinaboli</i> Pessagno, 1976	0.6
<i>Archaeodictyomitra</i> cf. <i>A. lamellicostata</i> (Foreman, 1968)	1.1
<i>Archaeodictyomitra</i> ? sp. 1	0.6
<i>Archaeodictyomitra</i> ? sp. 2	16.1
<i>Dictyomitra</i> sp. 1	0.6
<i>Dictyomitra</i> sp. 2	13.2
<i>Mita regina</i> ? (Campbell & Clark, 1944)	0.6
<i>Amphipyndax tylotus</i> Foreman, 1978	6.9
<i>Stichomitra asymbatos</i> Foreman, 1968	4.6
<i>Stichomitra</i> ? sp. 1	2.3
<i>Stichomitra</i> ? sp. 2	10.3
<i>Rhopalosyringium magnificum</i> Campbell & Clark, 1944	9.7
<i>Rhopalosyringium kleinum</i> Empson-Morin, 1981	1.1
<i>Botryometra heros</i> (Campbell & Clark, 1944)	2.9
<i>Cryptamphorella</i> sp.	4.6
<i>Theocapsomma</i> sp.	0.6
<i>Praeconocaryomma californiensis</i> Pessagno, 1976	10.3
<i>Alievium</i> ? sp.	3.4
<i>Paronaella</i> ? sp.	0.6
<i>Orbiculiforma</i> sp. 1	1.1
<i>Orbiculiforma</i> sp. 2	1.7
<i>Crucella</i> sp.	1.7
<i>Tholodiscus</i> sp.	2.9
<i>Spumellaria</i> gen. et sp. indet.	2.3

original opaline skeletons replaced by calcium carbonate (see Material and methods section) and secure specific identifications are only possible for those species with sturdy skeletons. This feature strongly suggests a preservational bias, being the studied fauna not representative of the original biocenosis and, consequently, hampering a detailed paleobiogeographic analysis. However, some inferences can be traced regarding the paleobiogeographic affinity of the studied assemblage, as well as its probable depth preference. According to the Empson-Morin's (1984) paleobiogeographic model, based on Campanian radiolarian faunas, the studied assemblage typify a low to mid latitude one, due to the dominance of species of *Amphipyndax* and *Dictyomitra*, as well as the occurrence of *Rhopalosyringium magnificum*. Besides, the absence of *Phaseliforma* Pessagno, 1972 species and "notched" *Orbiculiforma* also reinforces the low to intermediate latitudinal character of the studied assemblage (see Empson-Morin 1984). As demonstrated in Table 1, the studied assemblage is a nassellarian-dominated one, both in richness

and abundance. According to Empson-Morin's (1984) depth zonal scheme, nassellarians are more abundant in both shallow (middle to outer neritic) and deep (lower bathyal to abyssal) water environments. Herein it is suggested that the studied assemblage is a lower bathyal to abyssal one, due to the quite equitable abundances of multicyrtid nassellarians, including many forms of *Dictyomitra*, *Amphipyndax* and *Stichomitra*. Finally, the stratigraphic and geographic closely related radiolarian assemblages described by Aumond *et al.* (2009) seem to present the same faunal patterns, allowing to infer a similar paleobiogeographic and paleobathymetric affinity.

As taxonomic works are prerequisite for biostratigraphic and paleobiogeographic schemes, the description of additional Maastrichtian faunas is meaningful. Future works on radiolarian faunas of this age could confirm the stratigraphical ranges of some Upper Cretaceous taxa, as presented in this study, and contribute to the better understanding of the Upper Cretaceous (Maastrichtian) radiolarian paleobiogeography.

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