

Late Cretaceous and Paleogene Radiolaria from the Nicoya Peninsula, Costa Rica: a tectonostratigraphic application

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ABSTRACT: Detailed field mapping and paleontological dating in the central and southeastern Nicoya Peninsula has revealed Late Cretaceous and Paleogene radiolarian-bearing siliceous mudstones. These rocks belong to two terranes (Matambú and Manzanillo) that are partially contemporaneous with the Nicoya Complex, but are genetically different. While the Nicoya Complex is formed exclusively by intraplate igneous rocks with associated radiolarites, the studied sections include variable amounts of arc-derived volcanic and terrigenous materials. These fore-arc terranes include mafic to intermediate volcanoclastics and associated pelagic and hemipelagic rocks rich in biogenic silica. Radiolarian preservation in these sediments is often enhanced by the presence of silica-saturated volcanic tuffs and debris. Seven out of 29 samples from different outcrops yielded relatively well-preserved radiolarian faunas. In total, 60 species belonging to 34 genera were present in these faunas, ranging in age from middle Turonian-Santonian to late Thanetian-Ypresian.

INTRODUCTION

Several studies have been published on Late Cretaceous radiolarians from Costa Rica (Schmidt-Effing 1980, Baumgartner 1984b, Baumgartner et al. 2000, Popova et al. 2000, Denyer and Baumgartner 2006). Paleogene radiolarians have been mentioned to date pelagic rocks in Southern Costa Rica (Azéma et al. 1983, Di Marco 1994, Di Marco et al. 1995) but have not been illustrated. Radiolarian biostratigraphy has the potential to provide an accurate biochronologic framework for the many Upper Cretaceous and Paleogene pelagic and hemipelagic rock units in the Nicoya Peninsula (text-fig. 1), which until now have been poorly dated. Some of these formations overlie the relatively well-dated Nicoya Complex s. str. (Denyer and Baumgartner 2006), while others belong to different terranes that are partial time-equivalents of the Nicoya Complex. In this paper we report the results of a study of Late Cretaceous and Paleogene radiolarian-bearing siliceous mudstones and cherts from the central and southeastern Nicoya Peninsula (text-fig. 1), which do not belong to the Nicoya Complex. During our field campaigns from 2000 to 2005, we collected 29 samples for radiolarian dating in the Nicoya Peninsula, of which 7 yielded identifiable radiolarians.

The radiolarian biochronology for the Late Cretaceous is based on a compilation of radiolarian ranges published by Riedel and Sanfilippo (1974), Dumitrica (1975), Foreman (1975, 1977), Pessagno (1976), Taketani (1982), Sanfilippo and Riedel (1985), Schaaf (1985), Thurow (1988), O'Dogherty (1994), Hollis and Kimura (2001), Vishnevskaya (2001). The Paleogene sample was dated on the basis of Foreman (1973), Sanfilippo and Riedel (1973), Nishimura (1987, 1992), Sanfilippo and Nigrini (1998a, b).

Geological setting

Late Cretaceous radiolarian-bearing siliceous mudstones and cherts from the central and southeastern Nicoya Peninsula are associated with arc-derived mafic to intermediate volcanoclastics. In these sediments, the presence of silica-saturated volcanic tuffs and debris appears to have enhanced radiolarian preservation. These rocks belong to two fore-arc terranes, the Manzanillo and Matambú Terranes (Flores et al. 2004, 2005) that are partially contemporaneous with the Nicoya Complex s. str. (Denyer

and Baumgartner 2006), but are genetically different (text-fig. 2). Indeed, the Nicoya Complex contains only intraplate igneous rocks associated with radiolarites.

The two terranes and the Nicoya Complex share a common upper Campanian to Eocene overlap sequence with paralic to pelagic sediments at its base. This common lithostratigraphy indicates that they were juxtaposed by the late Campanian.

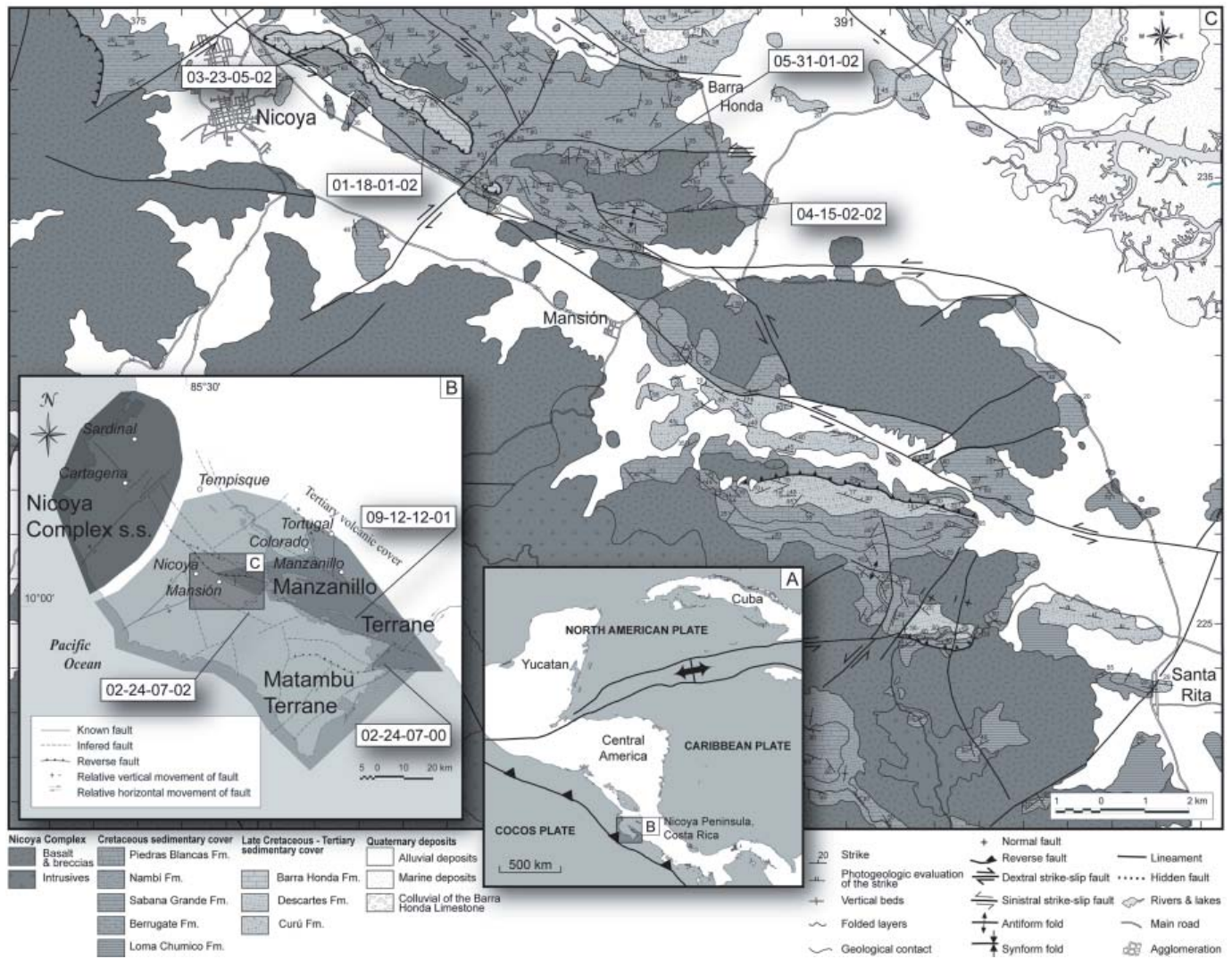
The single Paleogene sample studied comes from the Thanetian to Bartonian siliceous pelagic interval commonly observed in this overlap sequence (Baumgartner et al. 1984). However, it is from an outcrop previously placed in the Upper Cretaceous Sabana Grande Formation.

Manzanillo Terrane

The Manzanillo Terrane is floored by a toleitic basaltic basement and the Tortugual picritic suite of Turonian age (89 Ma, Alvarado et al. 1997). The picrites are intruded by alkaline basalts and gabbros. This basement is covered by the Berrugate Formation, a thick hemipelagic-turbiditic sequence containing arc-derived volcanoclastic deposits (Flores et al. 2003a, b), that must be late Turonian or younger. On the other hand, this formation is older than late Campanian, because it is unconformably overlain by the overlap sequence discussed below (text-fig. 2). The bituminous lithologies in this formation were previously included within the Loma Chumico Formation (Calvo and Bolz 1994, Calvo 1998), which is Albian in age, based on ammonites reported by Azéma et al. (1979). This caused confusion in subsequent paleogeographic and geodynamic interpretations (Frisch et al. 1992, Meschede and Frisch 1998, Pindell et al. 2005).

Matambú Terrane

The Matambú Terrane comprises a toleitic basaltic basement of pre-late Albian age, overlain by upper Albian bituminous, siliceous shales (Loma Chumico Formation, Azéma et al. 1979, Flores et al. 2003b, Denyer et al. 2005). This formation is thermally affected by younger basaltic flows and intrusives. The Loma Chumico Formation is overlain by pelagic, hemipelagic/turbiditic siliceous and calcareous shales and mudstones of the Sabana Grande Formation (Dengo 1962), dated so far only by



TEXT-FIGURE 1

A. Location map, Central America; B. Tectonic sketch map of the Nicoya Peninsula with location of sampled outcrops (02-24-07-00, 09-12-12-01, 02-24-07-02) and geographic localities of text-figure 2; C. Geological map of Matambú area (modified from Flores et al. 2003b) with location of samples (04-15-02-02, 05-31-01-02, 03-23-05-02, 01-18-01-02).

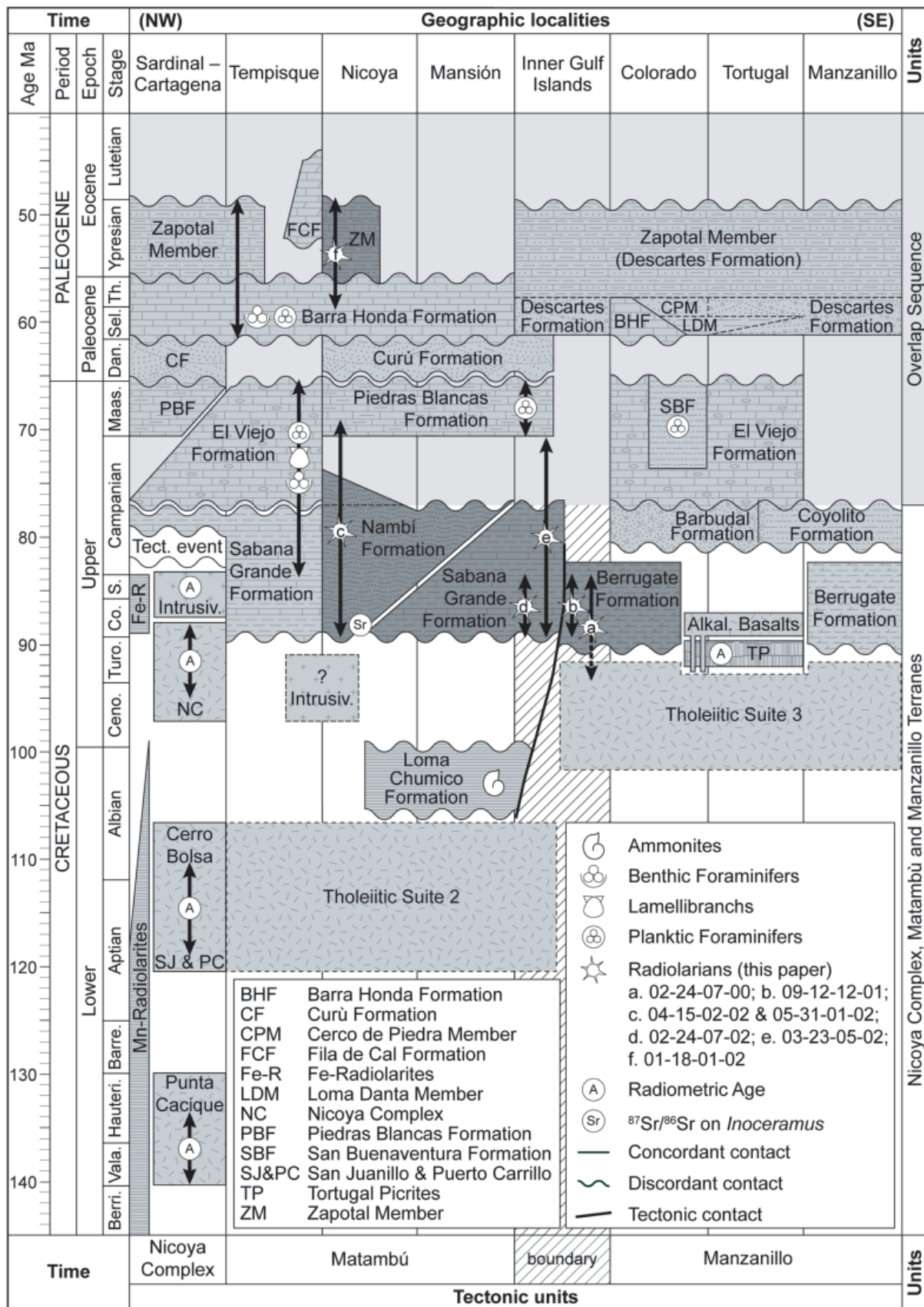
superposition as Cenomanian-Turonian (Flores et al. 2003b). The overlying Nambí Formation is characterized by volcanoclastic turbidities derived from the Nicoya Complex. An $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic value of 0.70738 from *Inoceramus* shell fragments is interpreted as Coniacian (Flores et al. 2003b). The top of Nambí is marked by the presence of reworked upper Campanian shallow water bioclasts derived from rudist bivalves biostromes of the El Viejo Formation (Jaccard et al. 2001, Flores et al. 2003a) that crop out in the Northern Nicoya Peninsula. These beds mark the transition to the overlap sequence (see below).

Nicoya Complex

The Nicoya Complex is composed of plateau basalts and intrusives yielding Berriasian to Campanian Ar/Ar ages (Sinton et al. 1997, Hoernle et al. 2004), which are mostly in intrusive contact with Middle Jurassic to Santonian radiolarites (Baumgartner 1984b). This area corresponds with the Nicoya Complex s. str. (Denyer and Baumgartner 2006).

Overlap Sequence

The overlap sequence on all three terranes records an upper Campanian-Maastrichtian paleogeographic setting that ranges from continental or nearshore to pelagic environments (text-fig. 2). The shallow water El Viejo Formation and its periplatform equivalents rest unconformably on the three terranes of the Nicoya Peninsula discussed above, and on the Santa Elena Ultramafic Unit (Schmidt-Effing 1974, Baumgartner et al. 1984, Seyfried and Sprechmann 1985, 1986). This formation is generally dated as late Campanian by the presence of the larger foraminifer *Pseudorbitoides israelskyi* (Seyfried and Sprechmann 1985, 1986, Baumgartner-Mora and Denyer 2002). The nearshore conglomeratic Barbudal Formation (Rivier 1983) reflects uplift and subaerial erosion of the basement of the Manzanillo Terrane. The shallow water rudist bivalves and larger foraminifer-bearing El Viejo Formation caps outer tectonic highs of the uplifted volcanic basement. Other less uplifted areas are covered by pelagic limestone containing planktonic foraminifera (Golfito Formation, Baumgartner et al. 1984, Piedras Blancas For-



TEXT-FIGURE 2
 Berriasian to Lutetian tectono-stratigraphic column of the Nicoya Peninsula, Costa Rica. The bottom part of the figure illustrates the formations belonging to the Nicoya Complex, the Matambú and Manzanillo Terranes, whereas the top part of the figure represents the formations of the overlap sequence. The formations from which the samples of this study come from are in dark grey. The geographic localities are located on text-figure 1B.

mation, Flores et al. 2003b), which is late Campanian to early Maastrichtian age based on identification of the *Globotruncana ventricosa*, *G. calcarata*, *G. falsostuarti*, *Gansserina gansseri* and *Abathomphalus mayaroensis* foraminiferal zones and magnetostratigraphy (Di Marco 1994, Di Marco et al. 1995, Flores et al. 2003b). Redeposited shallow-water bioclasts, derived from the El Viejo Formation also indicate the same age.

MATERIAL AND LOCALITIES

The sample locations are given with coordinates (kilometers in Costa Rica Lambert Nord System) based on the 1:50 000 scale topographic maps of the Instituto Geográfico Nacional, Edición 1 IGNCR (see also text-fig. 1). The remaining samples material and SEM stubs are stored in the Museum of Geology, University of Lausanne, Switzerland (no. MGU 97001–97007).

Manzanillo Terrane

Two samples come from the Berrugate Formation, a thick hemipelagic-turbiditic sequence containing arc-derived volcanoclastic deposits.

Sample 02-24-07-00 – Cedros Island
(204.1N/440.3E, Golfo quadrangle)

The Cedros Island is approximately located 2 kilometers east of the Nicoya Peninsula. The studied outcrop is situated in the north

beach of the island, Playa Matapalo (text-fig. 1). It comprises a 20 meters thick sequence of the Berrugate Formation consisting of centimeter to decimeter bedded grey to green volcanoclastic turbidites with planar and cross laminations, and interturbidite siliceous mudstone sampled for radiolaria. This lithology is separated by a 7 meters gap from the underlying Nicoya Complex sensu lato.

Sample 09-12-12-01 – Caballo Island
(219.4N/428.3E, Golfo quadrangle)

The Caballo Island is located in the southeast of the Gulf of Nicoya, about 4 kilometers north of the village of Cabo Blanco. The sample comes from an outcrop situated on the north coast of the island, approximately 1 kilometer east from Playa Coronado (text-fig. 1). The sampled lithology is very similar to the one of the previous site and corresponds to the topmost member of the turbiditic sequence of the Berrugate Formation.

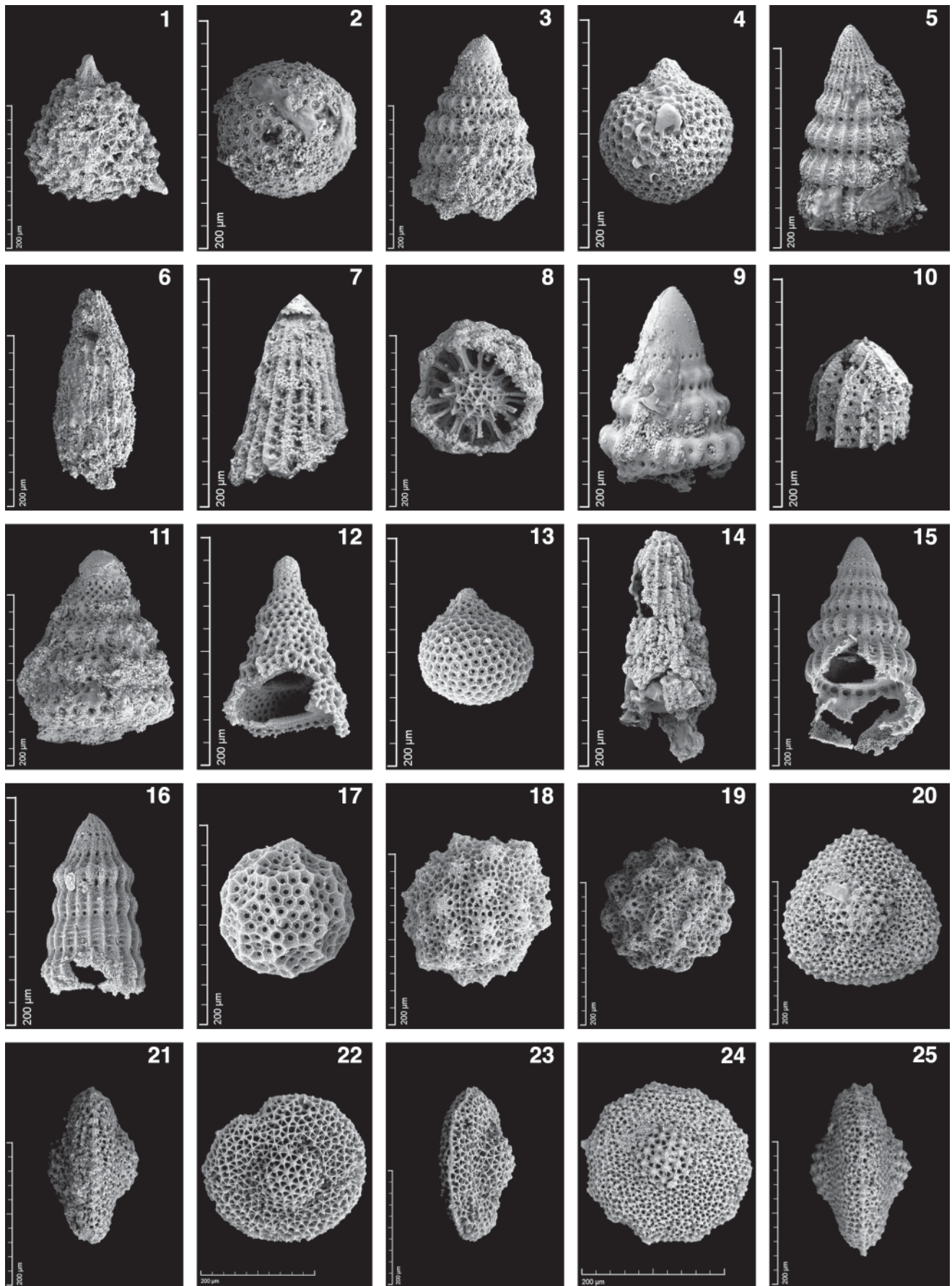
Matambú Terrane

The Nambí Formation consists of volcanoclastic and calcareous turbidites that intervene between two pelagic to hemipelagic sequences of the Sabana Grande and Piedras Blancas Formations (text-fig. 2). Both samples collected from the Nambi Formation come from the eastern side of the Cerro Obispo basaltic massive approximately located 7 kilometers east from the town of Nicoya (text-fig. 1) and correspond to the upper member of the Nambi Formation.

PLATE 1

SEM-illustrations of Late Cretaceous and Paleocene Radiolaria from the Nicoya Peninsula, Costa Rica: Berrugate Formation, samples 02-24-07-00 (figs. 1–11) and 09-12-12-01 (figs. 12–25). The numbers of illustrations in this plate correspond to those in table 1. Markers on all figures = 200µm.

1	<i>Alievium gallowayi</i> (White), 02-24-07-00, Berrugate Formation;	12	<i>Amphipyndax stocki</i> (Campbell and Clark), 09-12-12-01, Berrugate Formation;
2	<i>Archaeocenosphaera</i> sp., 02-24-07-00, Berrugate Formation;	13	<i>Cryptamphorella conara</i> (Foreman), 09-12-12-01, Berrugate Formation;
3	<i>Crolanium</i> sp., 02-24-07-00, Berrugate Formation;	14	<i>Dictyomitra</i> cf. <i>montisserei</i> (Squinabol), 09-12-12-01, Berrugate Formation;
4	<i>Cryptamphorella conara</i> (Foreman), 02-24-07-00, Berrugate Formation;	15	<i>Dictyomitra formosa</i> Squinabol, 09-12-12-01, Berrugate Formation;
5	<i>Dictyomitra formosa</i> Squinabol, 02-24-07-00, Berrugate Formation;	16	<i>Dictyomitra koslovae</i> Foreman, 09-12-12-01, Berrugate Formation;
6	<i>Dictyomitra</i> aff. <i>montisserei</i> (Squinabol), 02-24-07-00, Berrugate Formation;	17	<i>Hemicryptocapsa polyhedra</i> Dumitrica, 09-12-12-01, Berrugate Formation;
7	<i>Dictyomitra</i> sp., 02-24-07-00, Berrugate Formation;	18	<i>Praeconocaryomma</i> aff. <i>lipmanae</i> Pessagno, 09-12-12-01, Berrugate Formation;
8	<i>Praeconocaryomma universa</i> Pessagno, 02-24-07-00, Berrugate Formation;	19	<i>Praeconocaryomma universa</i> Pessagno, 09-12-12-01, Berrugate Formation;
9	<i>Pseudodictyomitra</i> sp. A, 02-24-07-00, Berrugate Formation;	20, 21	<i>Pseudoaulophacus floresensis</i> Pessagno, 09-12-12-01, Berrugate Formation;
10	<i>Rhopalosyringium</i> sp. A, 02-24-07-00, Berrugate Formation;	22, 23	<i>Pseudoaulophacus lenticulatus</i> (White), 09-12-12-01, Berrugate Formation;
11	<i>Stichomitra</i> aff. <i>parapedhia</i> Bragina and Bragin, 02-24-07-00, Berrugate Formation;	24, 25	<i>Pseudoaulophacus pargueraensis</i> Pessagno, 09-12-12-01, Berrugate Formation.



Sample 04-15-02-02 – near Cerro Piedra Amarilla (234.2N/386.7E, Matambú quadrangle)

The sampled lithology consists of a tectonized, 20 to 60 meters thick sequence of centimeter to decimeter bedded, grayish to purplish siliceous mudstone with interbeds and lenses of brown to red shale.

Sample 05-31-01-02 – Quebrada Enmedio (235.2N/386.0E, Matambú quadrangle)

The lithology is similar to the previous sample and comes from an outcrop very close in distance from the underlying basalts (text-fig. 2).

The Sabana Grande Formation consists of pelagic, hemipelagic and turbiditic siliceous and calcareous shales and mudstones. Two samples were collected from this formation.

Sample 02-24-07-02 – Road Vista del Mar to Zapotal (220.0N/394.6E, Cerro Azul quadrangle)

This sample comes from an outcrop in a small quarry located approximately 500 meters on the road west of Vista del Mar (text-fig. 2). This outcrop corresponds to the lower part of the Sabana Grande Formation. It is composed at its base of greyish and brownish siliceous mudstones that gradually pass upsection to brown marls. The sample comes from the first lithology.

Sample 03-23-05-02 – North of Finca Espavelar, Guatil (238.3N/380.3E, Matambú quadrangle)

The outcrop is situated 2.5 kilometers northeast of the town of Nicoya (text-fig. 1) and consists of alternating green-brownish siliceous shale and grey-greenish siliceous mudstone. This outcrop corresponds to the upper part of the Sabana Grande Formation near the contact with the overlying Nambi Formation (text-fig. 2).

Overlap Sequence

Sample 01-18-01-02 – Quebrada Gallina in the Cerro Pederal (236.5N/381.4E, Matambú quadrangle)

The sample comes from one of the small tectonized outcrops of greenish-grey siliceous mudstone, that occur along the overthrusts between the Sabana Grande and Barra Honda formations located east of the of Nicoya (text-fig. 1).

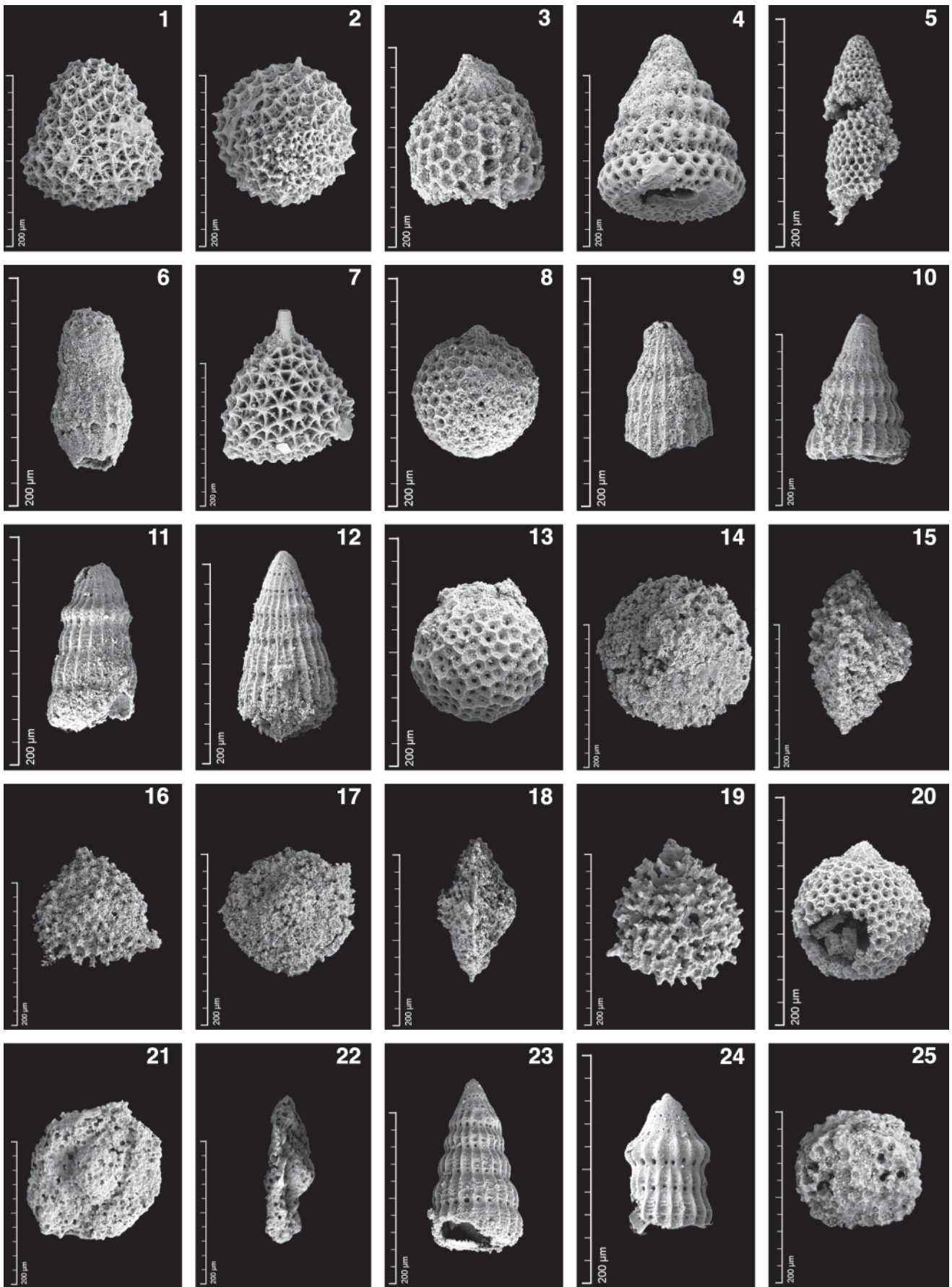
EXTRACTION METHOD

The dominant radiolarian-bearing lithology of the studied samples is siliceous limestone. In this type of rock, radiolarians are often replaced by calcite and are difficult to extract. When radiolarians are unaltered or altered to opal-CT or quartz they are easier to extract. This can be tested in the field by etching the sample with dilute hydrochloric acid (HCl, approximately 20%) and determining with a hand lens whether the radiolarians etch out in relief (Pessagno 1976).

PLATE 2

SEM-illustrations of Late Cretaceous Radiolaria from the Nicoya Peninsula, Costa Rica: Berrugate Formation, sample 09-12-12-01 (figs. 1–7); Nambí Formation, samples 04-15-02-02 (figs. 8–18) and 05-31-01-02 (figs. 19–25). The numbers of illustrations in this plate correspond to those in table 1. Markers on all figures = 200µm.

- | | | | |
|------|---|--------|---|
| 1, 2 | <i>Pyramispongia</i> (?) sp., 09-12-12-01, Berrugate Formation; | 13 | <i>Hemicryptocapsa</i> cf. <i>polyhedra</i> Dumitrica, 04-15-02-02, Nambí Formation; |
| 3 | <i>Rhopalosyringium</i> sp. B, 09-12-12-01, Berrugate Formation; | 14, 15 | <i>Patellula</i> cf. <i>cognata</i> O'Dogherty, 04-15-02-02, Nambí Formation; |
| 4 | <i>Stichomitra</i> aff. <i>parapedhia</i> , Bragina & Bragin, 09-12-12-01, Berrugate Formation; | 16 | <i>Pseudoaulophacus</i> cf. <i>floresensis</i> Pessagno, 04-15-02-02, Nambí Formation; |
| 5 | <i>Stichomitra</i> aff. <i>communis</i> Squinabol, 09-12-12-01, Berrugate Formation; | 17, 18 | <i>Pseudoaulophacus</i> sp. A, 04-15-02-02, Nambí Formation; |
| 6 | <i>Theocampe salillum</i> Foreman, 09-12-12-01, Berrugate Formation; | 19 | <i>Alievium</i> sp. A, 05-31-01-02, Nambí Formation; |
| 7 | <i>Alievium gallowayi</i> (White), 09-12-12-01, Berrugate Formation; | 20 | <i>Cryptamphorella conara</i> (Foreman), 05-31-01-02, Nambí Formation; |
| 8 | <i>Cryptamphorella conara</i> (Foreman), 04-15-02-02, Nambí Formation; | 21, 22 | <i>Dactyliosphaera</i> (?) aff. <i>silviae</i> Squinabol, 05-31-01-02, Nambí Formation; |
| 9 | <i>Dictyomitra</i> cf. <i>montisserei</i> (Squinabol), 04-15-02-02, Nambí Formation; | 23 | <i>Dictyomitra formosa</i> Squinabol, 05-31-01-02, Nambí Formation; |
| 10 | <i>Dictyomitra formosa</i> Squinabol, 04-15-02-02, Nambí Formation; | 24 | <i>Dictyomitra koslovae</i> Foreman, 05-31-01-02, Nambí Formation; |
| 11 | <i>Dictyomitra koslovae</i> Foreman, 04-15-02-02, Nambí Formation; | 25 | gen. sp. indet. (see also pl. 3, fig.1), 05-31-01-02, Nambí Formation. |
| 12 | <i>Dictyomitra</i> cf. <i>multicostata</i> Zittel, 04-15-02-02, Nambí Formation; | | |



The samples were selected by examination of thin sections for well-preserved siliceous radiolarians. The following procedure was used for the extraction of siliceous Radiolaria:

- 1) Samples were crushed to fragments <2-3cm in size and placed in 1-liter plastic jars;
- 2) Concentrated hydrochloric acid (32%) was poured on the crushed samples until the reaction ceased and all the exposed calcium carbonate was dissolved. This was done in order to avoid the formation of a thin layer of fluorite (CaF₂) around the samples during the hydrofluoric acid (HF) treatment (see below). Such a layer of fluorite severely reduces the efficiency of the hydrofluoric acid processing by protecting the samples. Some of the residues were checked after the hydrochloric acid treatment for radiolarians. However, none identifiable material was present and thus these residues were not kept.
- 3) Samples were rinsed and placed in plastic bowls;
- 4) Enough dilute hydrofluoric acid (4%) was poured on the samples to submerge them entirely and the bowls were sealed (for security and to stack them);
- 5) The reaction was allowed to continue for as long as 24 hours;

- 6) Samples were wet-sieved through 400µm and 60µm sieves retaining the 60 µm – 400 µm fraction of the residue;
- 7) Residues were rinsed and then dried in an oven;
- 8) Points 4) to 7) were repeated 3 times for each sample.

RADIOLARIAN BIOCHRONOLOGY

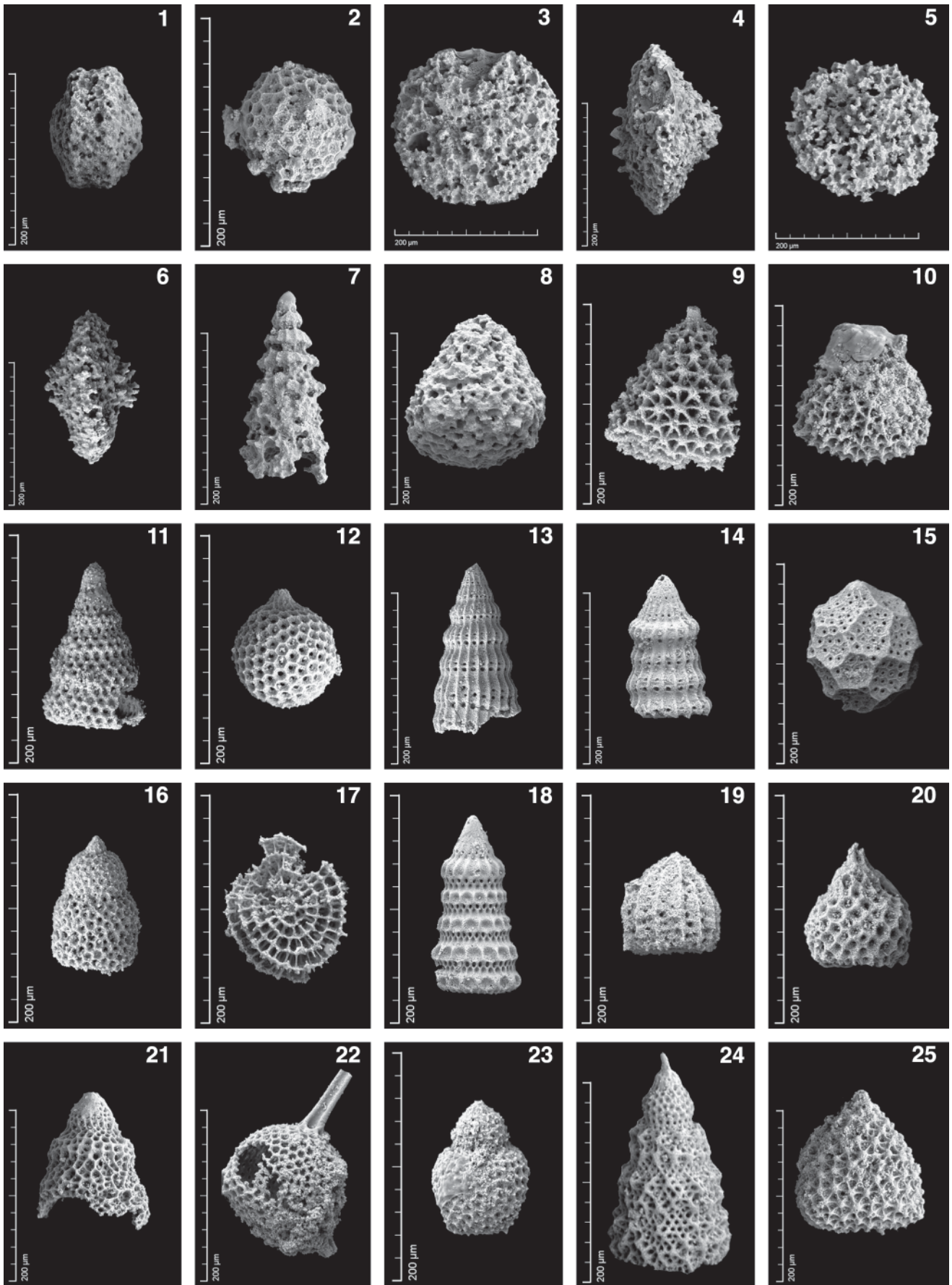
Mesozoic Radiolarian biochronology has made great progress in the past two decades. However, when we tried to date our assemblages with the existing Late Cretaceous zonations we met considerable problems.

Sanfilippo and Riedel (1985) proposed the first biostratigraphic synthesis for Cretaceous radiolarians, based on earlier work in DSDP sites and land-based sections from Japan and Northern Italy. Because many researchers consider this synthesis as the standard low-latitude radiolarian zonation, we tried to apply it to our data. We quickly realised that the co-occurrences of species in our data were not compatible with the ranges recorded by Sanfilippo and Riedel (1985). Indeed, it appears that some of the ranges are inconsistent with the ranges established by earlier studies. For instance, a number of species that successively ap-

PLATE 3

SEM-illustrations of Late Cretaceous and Paleocene Radiolaria from the Nicoya Peninsula, Costa Rica: Nambí Formation, sample 05-31-01-02 (figs. 1–8); Sabana Grande Formation, samples 02-24-07-02 (figs. 9–24) and 03-23-05-02 (fig. 25). The numbers of illustrations in this plate correspond to those in table 1. Markers on all figures = 200µm.

1	Gen. sp. indet. (see also pl. 2, fig. 25), 05-31-01-02, Nambí Formation;	15	<i>Hemicryptocapsa polyhedra</i> Dumitrica, 02-24-07-02, Sabana Grande Formation;
2	<i>Hemicryptocapsa</i> cf. <i>polyhedra</i> Dumitrica, 05-31-01-02, Nambí Formation;	16	<i>Lithocampe manifesta</i> (Foreman), 02-24-07-02, Sabana Grande Formation;
3, 4	<i>Patellula</i> cf. <i>cognata</i> O'Dogherty 05-31-01-02, Nambí Formation;	17	<i>Porodiscus</i> sp. 02-24-07-02, Sabana Grande Formation;
5, 6	<i>Pseudoaulophacus</i> sp. B, 05-31-01-02, Nambí Formation;	18	<i>Pseudodictyomitra</i> sp. C, 02-24-07-02, Sabana Grande Formation;
7	<i>Pseudodictyomitra</i> sp. B, 05-31-01-02, Nambí Formation;	19	<i>Rhopalosyringium</i> sp. A, 02-24-07-02, Sabana Grande Formation;
8	<i>Pyramispongia</i> (?) sp., 05-31-01-02, Nambí Formation;	20	<i>Rhopalosyringium</i> sp. C, 02-24-07-02, Sabana Grande Formation;
9	<i>Alievium gallowayi</i> (White), 02-24-07-02, Sabana Grande Formation;	21	<i>Torculum</i> sp., 02-24-07-02, Sabana Grande Formation;
10	<i>Alievium</i> sp. B, 02-24-07-02, Sabana Grande Formation;	22	<i>Triactoma cellulosa</i> Foreman, 02-24-07-02, Sabana Grande Formation;
11	<i>Amphipyndax stocki</i> (Campbell and Clark), 02-24-07-02, Sabana Grande Formation;	23	<i>Tricolocapsa</i> (?) sp., 02-24-07-02, Sabana Grande Formation;
12	<i>Cryptamphorella</i> cf. <i>conara</i> (Foreman), 02-24-07-02, Sabana Grande Formation;	24	<i>Xitus spicularius</i> (Aliev), 02-24-07-02, Sabana Grande Formation;
13	<i>Dictyomitra formosa</i> Squinabol, 02-24-07-02, Sabana Grande Formation;	25	<i>Alievium gallowayi</i> (White), 03-23-05-02, Sabana Grande Formation.
14	<i>Dictyomitra koslovae</i> Foreman, 02-24-07-02, Sabana Grande Formation;		



pear in their range chart during the Campanian (e.g. *Alievium gallowayi*, *Dictyomitra koslovae*, *Pseudoaulophacus floresensis*, *P. lenticulatus*, *P. pargueraensis*) were reported from Santonian or older sediments in earlier studies (Pessagno 1976), even some of those that were used for the zonation (Foreman 1975, Taketani 1982), as well as from other older sedimentary successions examined in more recent times (Okamura 1992, Denyer and Baumgartner 2006). We observed the co-occurrence of these species with *Hemicryptocapsa polyhedra* in our data, as shown already by Taketani (1982) and Schaaf (1985). The forementioned authors restrict this co-occurrence to a Coniacian-Santonian age, which is incompatible with the ranges expressed by Sanfilippo and Riedel (1985) for the series of species mentioned before.

The explanation of these staggered and later first occurrences in the range chart by Sanfilippo and Riedel (1985) lies in the way it was constructed: The authors applied the probabilistic stratigraphic procedure by Hay (1972), in order to reconcile the differences in the order of first and last appearances that typically exist in comparing sections. Baumgartner (1984a) has shown that probabilistic methods tend to shorten the ranges of taxa: The earliest and latest occurrences of a taxon are often rare and may be obliterated by lack of preservation. In a probabilistic approach these occurrences are statistically outnumbered by the central, more continuous occurrences of the taxon, which results in truncation of the earliest and latest appearances in a probabilistic range chart (see Baumgartner 1984a for details).

Probabilistic ranges cannot be used at their face value to date samples. At best, they serve to determine the most probable position of a particular assemblage, if the probability that the true sequence of events is known (Hay 1972, pp. 260, 261).

Our approach for the Late Cretaceous has been to seek for the maximal ranges of each species in combining the information from several authors. Differences between authors may result from locally incomplete ranges of radiolarian taxa, either due to paleobiogeographic or paleoecologic exclusions, or due to poor preservation or simply lack of suitable sediments or samples. Our way to establish radiolarian zonations is to maximise the range of each taxon within a broad paleobiogeographic realm by stacking the “partial” ranges expressed in each publication.

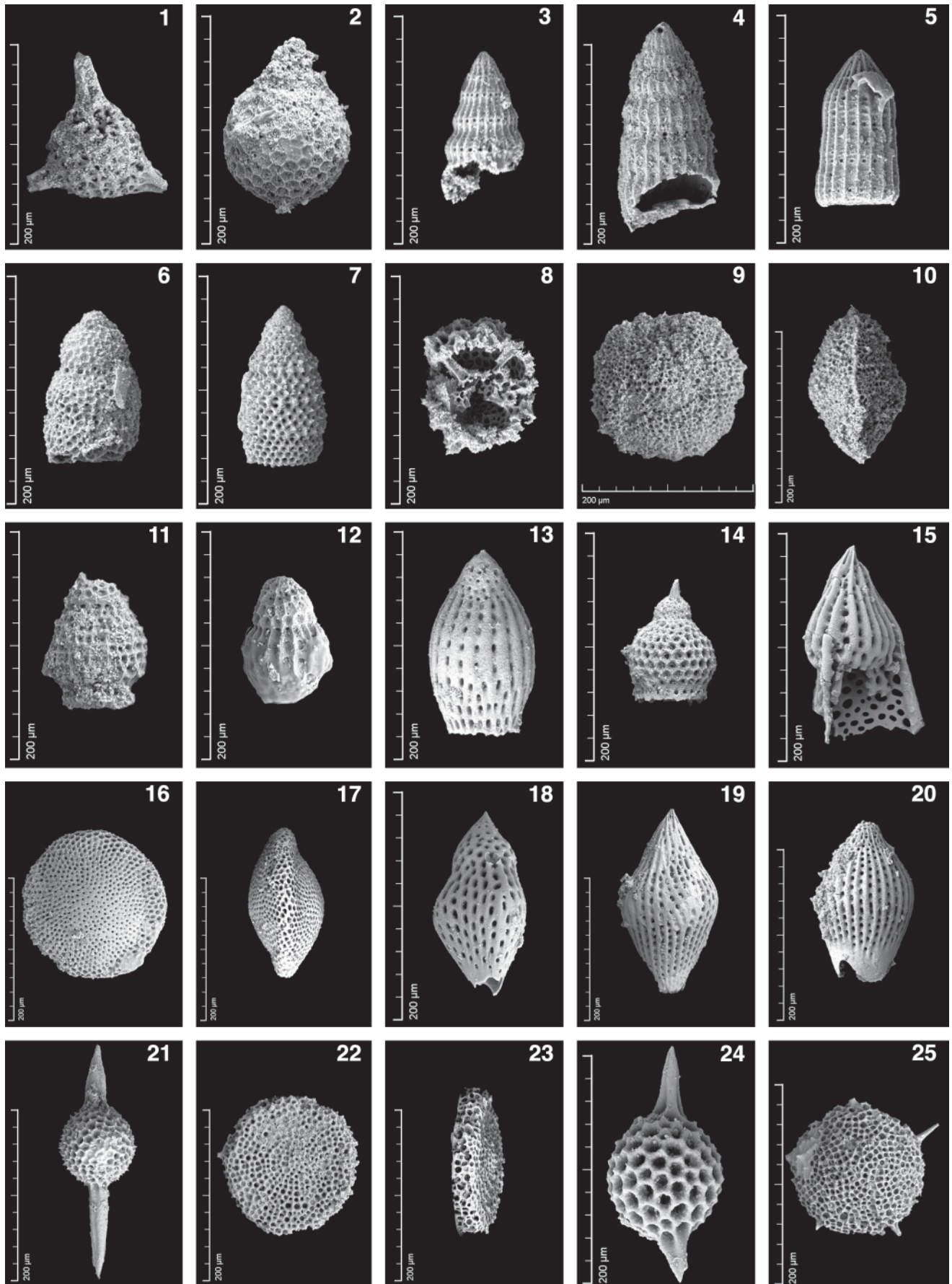
An ideal way to do this is through the creation of Unitary Associations (Baumgartner et al. 1980, Baumgartner 1984a, Guex 1991) using occurrence data for well-defined taxa from stratigraphically seriated samples, detached from the chronostratigraphic calibrations (Baumgartner et al. 1995). In such a way, we can construct a range chart for the Late Cretaceous that reflects maximal ranges of each taxon with respect to the maximal ranges of all other taxa. This work is now in progress (Jackett et al. 2002, Diserens et al. 2003, Jackett et al. this volume).

For this paper the comparison of ranges is based on the chronostratigraphic range of each taxon expressed by each author. We have stacked these ranges to obtain a maximum age range of

PLATE 4

SEM-illustrations of Late Cretaceous and Paleogene Radiolaria from the Nicoya Peninsula, Costa Rica: Sabana Grande Formation, sample 03-23-05-02 (figs. 1–12); Zapotal Member of Descartes Formation, sample 01-18-01-02 (figs. 13–25). The numbers of illustrations in this plate correspond to those in table 1. Markers on all figures = 200µm.

- | | | | |
|-------|---|--------|---|
| 1 | <i>Alievium superbum</i> (Squinabol), 03-23-05-02, Sabana Grande Formation; | 14 | <i>Calocycloma</i> cf. <i>ampulla</i> (Ehrenberg), 01-18-01-02, Zapotal Member of the Descartes Formation; |
| 2 | <i>Cryptamphorella</i> cf. <i>conara</i> (Foreman), 03-23-05-02, Sabana Grande Formation; | 15 | <i>Lychnocanium</i> (?) <i>carinatum</i> Ehrenberg, 01-18-01-02, Zapotal Member of the Descartes Formation; |
| 3 | <i>Dictyomitra formosa</i> Squinabol, 03-23-05-02, Sabana Grande Formation; | 16, 17 | <i>Phacodiscus rotula</i> Haeckel, 01-18-01-02, Zapotal Member of Descartes the Formation; |
| 4 | <i>Dictyomitra multicosata</i> Zittel, 03-23-05-02, Sabana Grande Formation; | 18 | <i>Phormocyrtis striata exquisita</i> (Koslova), 01-18-01-02, Zapotal Member of the Descartes Formation; |
| 5 | <i>Dictyomitra undata</i> Squinabol, 03-23-05-02, Sabana Grande Formation; | 19 | <i>Phormocyrtis</i> aff. <i>turgida</i> (Krasheninnikov), 01-18-01-02, Zapotal Member of the Descartes Formation; |
| 6 | <i>Lithocampe manifesta</i> (Foreman), 03-23-05-02, Sabana Grande Formation; | 20 | <i>Podocyrtis papalis</i> Ehrenberg, 01-18-01-02, Zapotal Member of the Descartes Formation; |
| 7 | <i>Lithostrobilus punctulatus</i> Pessagno, 03-23-05-02, Sabana Grande Formation; | 21 | <i>Spongattractus</i> sp., 01-18-01-02, Zapotal Member of the Descartes Formation; |
| 8 | <i>Praeconocaryomma universa</i> Pessagno, 03-23-05-02, Sabana Grande Formation; | 22, 23 | <i>Spongodiscus</i> sp., 01-18-01-02, Zapotal Member of the Descartes Formation; |
| 9, 10 | <i>Pseudoaulophacus</i> sp. C, 03-23-05-02, Sabana Grande Formation; | 24 | <i>Stylosphaera coronata</i> Ehrenberg, 01-18-01-02, Zapotal Member of the Descartes Formation; |
| 11 | <i>Theocampe</i> cf. <i>tina</i> (Foreman), 03-23-05-02, Sabana Grande Formation; | 25 | <i>Stylotrachus nitidus</i> Sanfilippo and Riedel, 01-18-01-02, Zapotal Member of the Descartes Formation. |
| 12 | <i>Theocampe salillum</i> Foreman, 03-23-05-02, Sabana Grande Formation; | | |
| 13 | <i>Buryella</i> sp., 01-18-01-02, Zapotal Member of the Descartes Formation; | | |



existence of each taxon. Important differences exist between the used zonations in terms of the quality of calibration of radiolarian events by planktonic foraminifera and nannofossils. Some of the diachronism of the chronostratigraphic ranges may be due to these differences. We acknowledge the possible errors that may arise using this procedure, but until a new biochronology based on Unitary Associations is ready, this is for us the best way to proceed. Applying the same principles, Bandini et al. (2006) could accurately match the ages of radiolarian and planktonic foraminifera in an earlier study of Turonian radiolarians from Eastern Greece.

The radiolarian biostratigraphy for the Late Cretaceous is based on work by Riedel and Sanfilippo (1974), Dumitrica (1975), Foreman (1975, 1977), Pessagno (1976), Taketani (1982), Sanfilippo and Riedel (1985), Schaaf (1985), Thurow (1988), O'Dogherty (1994), Hollis and Kimura (2001), Vishnevskaya (2001), while Foreman (1973), Sanfilippo and Riedel (1973), Nishimura (1987, 1992), Sanfilippo and Nigrini (1998a, 1998b) were used in dating the Paleogene sample.

Presentation of results

Seven out of 29 samples from different outcrops yielded relatively well-preserved radiolarians (table 1). In total, 60 species belonging to 34 genera were present in these 7 samples, ranging in age from Middle Turonian-Santonian to late Thanetian-Ypresian.

Manzanillo Terrane

The Berrugate Formation is a thick hemipelagic-turbiditic sequence containing arc-derived volcanoclastic deposits. Two of 9 processed samples give radiolarian ages.

Sample 02-24-07-00 – Cedros Island (204.1N/440.3E, Golfo quadrangle)

The occurrence of *Alievium gallowayi*, *Dictyomitra formosa* and *Praeconocaryomma universa* gives a middle Turonian-early Maastrichtian age.

Sample 09-12-12-01 – Caballo Island (219.4N/428.3E, Golfo quadrangle)

The occurrence of *Dictyomitra koslovae*, *Pseudoaulophacus floresensis*, *Theocampe salillum* and *Hemicryptocapsa polyhedra* gives a Coniacian-Santonian age.

The two radiolarian ages directly date the Berrugate Formation for the first time. As the sample 09-12-12-01 (Caballo Island) corresponds to the topmost member of the Berrugate Formation, the age of the sample 02-24-07-00 (Cedros Island) could be constrain to middle Turonian-Santonian. These ages allow us to determine the beginning of a volcanic arc activity on the western edge of the future Caribbean Plate at least since the Santonian. The duration of this activity is still poorly constrained. However, it seems to be restricted to the middle Turonian-early Campanian interval by stratigraphic superposition with El Viejo Formation (text-fig. 2). Moreover, we directly date rocks that were erroneously included with the Albian Loma Chumico Formation by previous authors (Calvo and Boltz 1994, Calvo 1998).

Matambú Terrane

The Nambí Formation consists of volcanoclastic (basaltic) and calcareous turbidites. It is assumed to be Coniacian to Campanian in age on the basis of an $^{87}\text{Sr}/^{86}\text{Sr}$ ratio measured in *Inoceramus*

(Coniacian in the lower part – see text-fig. 2) and overlying late Campanian rocks. Two of the 3 studied samples give radiolarian ages.

Sample 04-15-02-02 – near Cerro Piedra Amarilla (234.2N/386.7E, Matambú quadrangle) and Sample 05-31-01-02 – Quebrada Enmedio (235.2N/386.0E, Matambú quadrangle)

The occurrence of *Dictyomitra koslovae* and *Dictyomitra formosa* suggests a Coniacian-early Maastrichtian age, and thus supports the interpretation of $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic data from *Inoceramus*.

The Sabana Grande Formation consists of pelagic, hemipelagic and turbiditic siliceous and calcareous shales and mudstones. This formation is currently assumed to be of Cenomanian – Coniacian age (text-fig. 2). Two out of 12 samples yielded radiolarians.

Sample 02-24-07-02 – Road Vista del Mar to Zapotal (220.0N/394.6E, Cerro Azúl quadrangle)

The occurrence of *Dictyomitra koslovae* and *Hemicryptocapsa polyhedra* gives a Coniacian-Santonian age.

Sample 03-23-05-02 – North of Finca Espavelar, Guatil (238.3N/380.3E, Matambú quadrangle)

The occurrence of *Theocampe salillum* and *Alievium superbum* gives a Coniacian-Campanian age. These ages imply a significant stratigraphic gap between the underlying Albian Loma Chumico Formation and the Sabana Grande Formation.

Overlap Sequence

Sample 01-18-01-02 – Quebrada Gallina in the Cerro Pedernal (236.5N/381.4E, Matambú quadrangle)

This sample gives a late Thanetian-Ypresian age by the occurrence of *Lychnocanium* (?) *carinatum*, *Podocyrtilis papalis*, *Phormocyrtis striata exquisita* and *Stylotrochus nitidus*. This outcrop has been previously assigned to the Sabana Grande Formation on the basis of its very similar lithology (Flores et al. 2003b). However, the late Thanetian-Ypresian age indicates that this outcrop, located beneath an overthrust, should be assigned to the Zapotal Member of the Descartes Formation (Flores et al. 2003b). Similarly, other isolated outcrops of “Sabana Grande” lithologies are not stratigraphically constrained and could therefore have a different age. Biosiliceous pelagic sequences of Thanetian to Bartonian age have been identified in many areas of Costa Rica (Baumgartner et al. 1984).

CONCLUSION

This work shows that radiolarians can provide significant biostratigraphic control in the Nicoya Peninsula where very similar lithologies of different ages are present. Despite the possible uncertainties of their calibration, they become critical to constrain the tectonostratigraphic framework.

Two radiolarian samples directly date the Berrugate Formation for the first time (middle Turonian-Santonian and Coniacian-Santonian). These ages allow to determine a volcanic arc activity on the western edge of the future Caribbean Plate at least since the Santonian that could have lasted through the middle Turonian-early Campanian interval by stratigraphic superposition. Moreover on the basis of these radiolarian ages, the Loma

Chumico Formation of Albian age, and the Berrugate Formation of middle Turonian-early Maastrichtian age, can now be clearly differentiated.

Two radiolarian faunas of Coniacian-early Maastrichtian age from the Nambí Formation support an early Coniacian age determined from $^{87}\text{Sr}/^{86}\text{Sr}$ isotopes from *Inoceramus* (early Coniacian).

Two samples from the Sabana Grande Formation give a Coniacian-Santonian age and a Coniacian-Campanian age and indicate that there is a stratigraphic gap of ~10 million years between this formation and the underlying Albian Loma Chumico Formation.

One sample of Thanetian to Ypresian age from an outcrop that has been previously assigned to the Sabana Grande Formation should be assigned to the Zapotal Member of the Descartes Formation. Similarly, other isolated outcrops of "Sabana Grande" lithologies are not stratigraphically constrained and could therefore have a different age.

SYSTEMATIC PALEONTOLOGY

Only the radiolarian species considered important for the biostratigraphy of the studied samples are cited in the systematic part and are listed alphabetically. The synonymies given include the original description of each taxon and additional synonymies from the following publications: Foreman (1973, 1975, 1977), Sanfilippo and Riedel 1973, 1985, Riedel and Sanfilippo 1974, Dumitrica 1975, Pessagno 1976, Taketani 1982, Schaaf 1985, Nishimura 1987, 1992, Thurow 1988, O'Dogherty 1994, Hollis and Kimura 2001, Vishnevskaya 2001. For further synonymies, the reader is referred to these publications.

Alievium gallowayi (White)

Plate 1, figure 1; Plate 2, figure 7; Plate 3, figures 9, 25

Baculogypsina (?) *gallowayi* WHITE 1928, p. 305, pl. 41, figs. 9, 10.
Alievium gallowayi (White) – FOREMAN 1975, p. 613, pl. 1D, figs. 2, 3; pl. 5, fig. 11. – 1977, p. 315. – PESSAGNO 1976, p. 27, pl. 8, fig. 13, 14; pl. 9, fig. 1. – SANFILIPPO and RIEDEL 1985, p. 594, text fig. 6(1). – THUROW 1988, pp. 396, 397, pl. 2, fig. 3. – HOLLIS and KIMURA 2001, p. 245 – VISHNEVSKAYA 2001, p. 144, pl. 97, fig. 3.

Published ranges: middle Turonian-Coniacian to Santonian (Foreman 1975), early Santonian to late Campanian (Pessagno 1976), Santonian-Campanian to Maastrichtian (Foreman 1977), Campanian to Maastrichtian (Sanfilippo and Riedel 1985), middle Campanian to Maastrichtian (Thurow 1988), early Santonian to early Maastrichtian (Hollis and Kimura 2001), Coniacian to Campanian (Vishnevskaya 2001).

Composite range: middle Turonian-Coniacian to Maastrichtian

Alievium superbum (Squinabol)

Plate 4, figure 1

Theodiscus superbum SQUINABOL 1914, p. 217, pl. 20, fig. 4.
Pseudoaulophacus superbus (Squinabol) – RIEDEL and SANFILIPPO 1974, p. 780, pl. 3, figs. 1–3.
Alievium superbum (Squinabol) – DUMITRICA 1975, text-fig. 2.42. – PESSAGNO 1976, p. 27, pl. 3, fig. 12. – FOREMAN 1977, p. 315. – TAKETANI 1982, p. 51, pl. 10, fig. 8. – SANFILIPPO and RIEDEL 1985, 594, text-fig. 6.2. – SCHAAF 1985, p. 250, text-fig. 12. – THUROW 1988, p. 397, pl. 2, fig. 2. – O'DOGHERTY 1994, pp. 322, 323, pl. 59, figs. 14–18. – VISHNEVSKAYA 2001, pp. 144, 145, pl. 98, fig. 5; pl. 100, figs. 1, 2; pl. 115, fig. 7.

Published ranges: late Cenomanian (Dumitrica 1975), middle Turonian to late Campanian (Pessagno 1976), Cenomanian (Foreman 1977), Turonian to Coniacian (Taketani 1982), Turonian to Campanian (Sanfilippo and Riedel 1985), Turonian to Santonian (Schaaf 1985), late Cenomanian-early Turonian to middle Campanian (Thurow 1988), early Turonian (O'Dogherty 1994), late Albian to Campanian (Vishnevskaya 2001).

Composite range: late Albian to late Campanian

Amphipyndax stocki (Campbell and Clark)

Plate 1, figure 12; Plate 2, figure 11

Stichocapsa (?) *stocki* CAMPBELL and CLARK 1944, p.44, pl.8, figs. 31–33.

Amphipyndax stocki (Campbell and Clark) – RIEDEL and SANFILIPPO 1974, p. 775, pl. 15, fig. 11; pl. 11, figs. 1–3. – DUMITRICA 1975, text-fig. 2.23. – FOREMAN 1977, p. 315. – TAKETANI 1982, p. 52, pl. 2, figs. 9a, 9b; pl. 10, figs. 13, 14. – VISHNEVSKAYA 2001, p. 146, pl. 1, fig. 13; pl. 4, figs. 11–13; pl. 6, fig. 12; pl. 16, fig. 1; pl. 93, figs. 4,5; pl. 94, figs. 8, 10; pl. 99, figs. 1–3, 8; pl. 114, fig. 12.

Amphipyndax sp. TAKETANI 1982, p. 52, pl. 10, fig. 16.

Stichomitra stocki (Campbell and Clark) – O'DOGHERTY 1994, pp. 147, 148, 150, pl. 18, figs. 9–15.

Amphipyndax stocki (Campbell and Clark) group – HOLLIS and KIMURA 2001, p. 246.

Amphipyndax stocki (Campbell and Clark) var. A – VISHNEVSKAYA 2001, pp. 146, 147, pl.16, figs. 2–6; pl. 26, fig. 6; pl. 100, fig. 4; pl. 123, figs. 16–21, 23.

Amphipyndax stocki (Campbell and Clark) var. B – VISHNEVSKAYA 2001, p. 147, pl. 3, fig. 6; pl. 12, figs. 3, 5; pl. 15, figs. 1–5.

Amphipyndax stocki (Campbell and Clark) var. C – VISHNEVSKAYA 2001, p. 147, pl. 3, figs. 2, 4; pl. 14, figs. 1–3.

Published ranges: Barremian-Albian to Maastrichtian (Riedel and Sanfilippo 1974), late Cenomanian (Dumitrica 1975), Albian-early Santonian to Maastrichtian (Foreman 1977), Cenomanian to Santonian (Taketani 1982), late Cenomanian to early Turonian (O'Dogherty 1994), Albian-Cenomanian to Thanetian (Hollis and Kimura 2001), Barremian to Paleocene (Vishnevskaya 2001).

Composite range: Barremian to Thanetian

Cryptamphorella conara (Foreman)

Plate 1, figures 4, 13; Plate 2, figures 8, 20

Hemicryptocapsa conara FOREMAN 1968, p.35, pl. 4, figs. 11a, 11b.
Cryptamphorella conara (Foreman) – DUMITRICA 1975, text-fig. 2.28. – SANFILIPPO and RIEDEL 1985, p.613, text-fig. 12.1a–12.1c. – SCHAAF 1985, text-fig. 11. – THUROW 1988, pp. 399, 400, pl. 1, fig. 2; pl. 5, fig. 1. – HOLLIS and KIMURA 2001, p. 247. – VISHNEVSKAYA 2001, pp. 158, 159, pl. 22, fig. 4; pl. 76, fig. 2; pl. 79, fig. 2.

Published ranges: late Cenomanian (Dumitrica 1975), Albian to Maastrichtian (Sanfilippo and Riedel 1985), Albian to Santonian and younger (Schaaf 1985), Cenomanian and older to Maastrichtian (Thurow 1988), Albian to late Maastrichtian (Hollis and Kimura 2001), Albian to Late Cretaceous (Vishnevskaya 2001).

Composite range: Albian to late Maastrichtian

Dictyomitra formosa Squinabol

Plate 1, figures 5, 15; Plate 2, figures 10, 23; Plate 3, figure 13; Plate 4, figure 3

Dictyomitra formosa SQUINABOL 1904, p. 232, pl. 10, fig. 4. – PESSAGNO 1976, p. 51, pl. 8, figs. 10–12. – TAKETANI 1982, p. 58, pl. 4, figs. 6a–b; pl. 11, fig. 13. – SCHAAF 1985, text-fig. 12. – THUROW 1988, p. 400, pl. 1, figs. 23, 25. – O'DOGHERTY 1994, p. 80, pl. 4,

figs.8–12. – HOLLIS and KIMURA 2001, p. 249. – VISHNEVSKAYA 2001, p. 160, pl. 25, fig. 10.
Dictyomitra duodecimcostata (Squinabol) – FOREMAN 1975, p.614, pl.1G, figs. 5, 6; pl. 7, fig.8. – 1977, p. 315.

Published ranges: late Cenomanian-Turonian to Santonian (Foreman 1975), early Coniacian to early Campanian (Pessagno 1976), Coniacian-Santonian to late Campanian-early Maastrichtian (Foreman 1977), Coniacian to Santonian (Taketani 1982), Turonian to Santonian and younger (Schaaf 1985), late Turonian-Coniacian to middle Campanian (Thurrow 1988), late Albian to early Turonian (O'Dogherty 1994), Albian to early Maastrichtian (Hollis and Kimura 2001), Albian to Turonian (Vishnevskaya 2001).

Composite range: Albian to early Maastrichtian

***Dictyomitra koslovae* Foreman**

Plate 1, figure 16; Plate 2, figures 11, 24; Plate 3, figure 14

Dictyomitra torquata Foreman – RIEDEL and SANFILIPPO 1974, p. 778, pl. 5, figs. 1–4; pl. 14, fig. 2.
Dictyomitra koslovae FOREMAN 1975, p. 614, pl. 7, fig. 4. – 1977, p. 315. – TAKETANI 1982, p. 58, pl. 4, figs. 9, 10; pl. 11, figs. 14, 15. – HOLLIS and KIMURA 2001, p. 249. – VISHNEVSKAYA 2001, p. 160, pl. 94, figs. 1, 3; pl. 126, figs. 24–35.
Dictyomitra koslovae s.l. – SANFILIPPO and RIEDEL 1985, p. 599, text-fig. 7.4a–7.4e. – SCHAAF 1985, text-fig. 12. – THURROW 1988, p. 400, pl. 1, fig. 29.

Published ranges: Albian-Campanian to Campanian (Riedel and Sanfilippo 1974), Santonian? (Foreman 1975), Santonian-Campanian to Maastrichtian (Foreman 1977), Coniacian to Campanian (Taketani 1982), Campanian to Maastrichtian ? (Sanfilippo and Riedel 1985), younger than Santonian (Schaaf 1985), early-middle Campanian to late Campanian (Thurrow 1988), Coniacian to early Maastrichtian (Hollis and Kimura 2001), Coniacian to Campanian (Vishnevskaya 2001).

Composite range: Coniacian to Maastrichtian.

***Dictyomitra multicostata* Zittel**

Plate 4, figure 4

Dictyomitra multicostata ZITTEL 1876, p. 81, pl. 2, figs. 2–4. – PESSAGNO 1976, p. 52, pl. 14, figs. 4–9. – O'DOGHERTY 1994, pp. 82, 83, pl. 4, figs. 17–19. – HOLLIS AND KIMURA 2001, p. 249.

Published ranges: middle Campanian to Maastrichtian (Pessagno 1976), early Turonian (O'Dogherty 1994), Turonian to Danian (Hollis and Kimura 2001).

Composite range: early Turonian to Danian

***Hemicryptocapsa polyhedra* Dumitrica**

Plate 1, figure 17; Plate 3, figure 15

Hemicryptocapsa polyhedra DUMITRICA 1970, p. 72, pl. 14, figs. 85a–85c. – TAKETANI 1982, p. 66 pl. 7, figs. 5a, 5b. – SCHAAF 1985, text-fig. 11. – THURROW 1988, p. 401, pl. 1, fig. 1.

Published ranges: late ? Cenomanian to Coniacian (Taketani 1982), Albian to Santonian (Schaaf 1985), early Turonian (Thurrow 1988).

Composite range: Albian to Santonian

***Lychnocanium* (?) *carinatum* Ehrenberg**

Plate 4, figure 15

Lychnocanium carinatum EHRENBERG 1875, p. 78, pl. 8, fig. 5.
Lychnocanium (?) *carinatum* Ehrenberg – NISHIMURA 1987, p. 727, pl. 3, figs. 6, 11.
Theopodium aff. *Lychnocanium carinatum* Ehrenberg – NISHIMURA 1992, p. 356, pl. 7, fig. 12.

Published range: *Bekomacampechensis* Zone to *Phormocyrtis striata striata* Zone (Nishimura 1987, 1992) corresponding to Selandian (lower RP6) to uppermost Ypresian (RP9) (Sanfilippo and Nigrini, 1998a).

***Phacodiscus rotula* Haeckel**

Plate 4, figures 16, 17

Phacodiscus rotula HAECKEL 1887, p.424, pl. 35, fig. 7.

***Phormocyrtis striata exquisita* (Kozlova)**

Plate 4, figure 18

Podocyrtis exquisita Kozlova in KOZLOVA and GORBOVETZ 1966, p. 106, pl. 17, fig. 2.
Phormocyrtis striata exquisita (Kozlova) – FOREMAN 1973, p. 438, pl. 7, figs. 1–4, 7, 8; pl. 12, fig. 5. – NISHIMURA 1987, p. 727, pl. 2, fig. 13.

Published ranges: *Bekoma bidartensis* Zone and older to *Buryella clinata* Zone (Foreman 1973), lower *Bekoma campechensis* Zone to *Buryella clinata* Zone (Nishimura 1987).

Composite range: lower *Bekoma campechensis* Zone to *Buryella clinata* Zone corresponding to Selandian (RP6) to Ypresian (RP8) (Sanfilippo and Nigrini, 1998a).

***Podocyrtis papalis* Ehrenberg**

Plate 4, figure 20

Podocyrtis papalis EHRENBERG 1847, p. 55, fig. 2. – NISHIMURA 1987, p. 727, pl. 2, fig. 17.
Podocyrtis (podocyrtis) papalis Ehrenberg – SANFILIPPO and RIEDEL 1973, p. 531, pl. 20, figs. 11–14; pl. 36, figs. 2, 3.

Published ranges: *Bekoma bidartensis* Zone to *Podocyrtis mitra* Zone and younger (Sanfilippo and Riedel 1973), *Bekoma bidartensis* Zone to *Bekoma clinata* Zone (Nishimura 1987).

Composite range: *Bekoma bidartensis* Zone to *Podocyrtis mitra* Zone and younger corresponding approximately to Thanetian (RP7) to Bartonian (RP14) and younger (Sanfilippo and Nigrini, 1998a).

***Praeconocaryomma universa* Pessagno**

Plate 1, figures 8, 19; Plate 4, figure 8

Praeconocaryomma universa PESSAGNO 1976, p. 42, pl. 6, figs. 14–16. – TAKETANI 1982, p. 47, pl. 1, figs. 3a, 3b, 4; pl. 9, fig. 4.
Conocaryomma universa (Pessagno) – THURROW 1988, pp. 398, 399, pl. 2, fig. 18. – HOLLIS and KIMURA 2001, p. 247.
Praeconocaryomma ex gr. *universa* Pessagno – VISHNEVSKAYA 2001, p. 179, pl. 80, fig. 4; pl. 81, fig. 1.

Published ranges: early Coniacian to middle Campanian (Pessagno 1976), early Coniacian to early Santonian (Taketani 1982), late Cenomanian-early Turonian to middle Campanian (Thurrow 1988), Turonian to early Maastrichtian (Hollis and Kimura 2001), Santonian to Campanian (Vishnevskaya 2001).

Composite range: late Cenomanian-early Turonian to early Maastrichtian

Pseudoaulophacus floresensis Pessagno

Plate 1, figures 20, 21

Pseudoaulophacus floresensis PESSAGNO 1963, p. 200, pl. 2, figs. 2, 5; pl. 4, fig. 6, pl. 7, figs. 1–5. – PESSAGNO 1976, p. 28, pl. 9, fig. 6. – SANFILIPPO and RIEDEL 1985, pp. 595, 596, text-figs. 6.3a, 6.3b. – SCHAAF 1985, text-fig. 12. – THUROW 1988, p. 404, pl. 2, fig. 5. – HOLLIS and KIMURA 2001, p. 250. – VISHNEVSKAYA 2001, pp. 180, 181, pl. 18, fig. 3; pl. 98, fig. 7.

Published ranges: Santonian to late Campanian (Pessagno 1976), Campanian to Maastrichtian (Sanfilippo and Riedel 1985), Coniacian to Santonian and younger (Schaaf 1985), Campanian to Maastrichtian (Thurrow 1988), Santonian to early Maastrichtian (Hollis and Kimura 2001), Santonian to Campanian (Vishnevskaya 2001).

Composite range: Coniacian to Maastrichtian

Pseudoaulophacus lenticulatus (White)

Plate 1, figures 22, 23

Baculogypsina (?) *lenticulata* WHITE 1928, p. 306, pl. 41, figs. 9, 11. *Pseudoaulophacus lenticulatus* (White) – PESSAGNO 1976, p. 28, pl. 9, figs. 11, 12. – FOREMAN 1977, p. 315. – TAKETANI 1982, p. 51, pl. 10, fig. 11. – SANFILIPPO and RIEDEL 1985, p. 596, text-figs. 6.4a, 6.4b. – THUROW 1988, p. 404, pl. 2, fig. 6. – HOLLIS and KIMURA 2001, p. 250.

Published ranges: early Coniacian to late Campanian (Pessagno 1976), Santonian-Campanian to Campanian (Foreman 1977), Coniacian to Campanian (Taketani 1982), Campanian (Sanfilippo and Riedel 1985), Campanian (Thurrow 1988), Turonian to early Maastrichtian (Hollis and Kimura 2001).

Composite range: Turonian to early Maastrichtian

Pseudoaulophacus pargueraensis Pessagno

Plate 1, figure 24, 25

Pseudoaulophacus pargueraensis PESSAGNO 1963, p. 204, pl. 2, figs. 4, 7; pl. 6, figs. 4, 5. – FOREMAN 1975, p. 613, pl. 5, fig. 8. – 1977, p. 315. – RIEDEL and SANFILIPPO 1974, p. 780, pl. 2, figs. 12–14. – SANFILIPPO and RIEDEL 1985, p. 596, text-figs. 6.5a–6.5d. – SCHAAF 1985, text-fig. 12. – THUROW 1988, p. 404, pl. 2, fig. 7. – HOLLIS and KIMURA 2001, p. 250. – VISHNEVSKAYA 2001, p. 181, pl. 97, fig. 2.

Published ranges: Coniacian-Campanian to Campanian (Riedel and Sanfilippo 1974), Santonian ? (Foreman 1975), Santonian-Campanian to late Campanian-early Maastrichtian (Foreman 1977), Campanian (Sanfilippo and Riedel 1985), Turonian to Santonian (Schaaf 1985), Campanian (Thurrow 1988), Coniacian to early Maastrichtian (Hollis and Kimura 2001), Santonian to Campanian (Vishnevskaya 2001).

Composite range: Turonian to early Maastrichtian

Stylotrochus nitidus Sanfilippo and Riedel

Plate 4, figure 25

Stylotrochus nitidus SANFILIPPO and RIEDEL 1973, p. 525, pl. 13, figs. 9–14; pl. 30, figs. 7–10. – NISHIMURA 1987, p. 729, pl. 1, fig. 12. – NISHIMURA 1992, p. 328, pl. 2, fig. 1; pl. 12, fig. 8.

Published range: *Bekoma bidartensis* Zone and older to *Phormocyrtis striata striata* Zone (Sanfilippo and Riedel 1973), upper *Bekoma campechensis* Zone to *Phormocyrtis striata striata* Zone (Nishimura 1987, 1992),

Composite range: upper *Bekoma campechensis* Zone to *Phormocyrtis striata striata* Zone corresponding to Thanetian (upper RP6) to uppermost Ypresian (RP9) (Sanfilippo and Nigrini, 1998a).

Theocampe salillum Foreman

Plate 2, figure 6; Plate 4, figure 12

Theocampe salillum FOREMAN 1971, p. 1678, pl. 4, fig. 5. – 1977, p. 315. – RIEDEL and SANFILIPPO 1974, p. 780, pl. 11, figs. 8–10. – TAKETANI 1982, p. 53, pl. 2, fig. 14. – SANFILIPPO and RIEDEL 1985, p. 605, text-figs. 9.4a–9.4c. – SCHAAF 1985, text-fig. 12. – HOLLIS and KIMURA 2001, p. 252.

Published ranges: Coniacian-Campanian to Maastrichtian (Riedel and Sanfilippo 1974), early Santonian to late Campanian-early Maastrichtian (Foreman 1977), Coniacian to Campanian (Taketani 1982), Coniacian-Santonian to Campanian (Sanfilippo and Riedel 1985), Santonian and younger (Schaaf 1985), Coniacian to late Campanian (Hollis and Kimura 2001).

Composite range: Coniacian to Maastrichtian

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