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Coccolithophorids from the west coast of Baja California, Mexico

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Abstract

Studies on coccolithophorids in Mexico are rather scarce, probably due to the use of traditional methods for studying marine phytoplankton (e.g. collection, preservation and analysis). This is the first study of the coccolithophorid flora from west coast of Baja California, Mexico. Bottle samples (4 l) were taken at various depths (5, 25 and 50 m), at fixed stations located on perpendicular transects along the west coast of Baja California, considering three different zones: North, Central and South. A total of 32 samples were studied by optical and scanning electron microscopy, yielding 24 taxa identified (17 species and 5 nominal varieties, plus 2 different varieties). The coccolithophorid assemblages are considered subtropical and coastal (with many cosmopolitan taxa). *Emiliania huxleyi* and *Gephyrocapsa oceanica* were the most abundant (relative abundance) and widespread species in the study area. We report 15 new records for the Mexican Pacific. The zonal and vertical distribution of some taxa are briefly discussed, as well as the taxonomy of *Rhabdosphaera claviger*, *Helicosphaera carteri*, *H. hyalina* and related taxa.

Introduction

The coccolithophorids form a very important group of the marine phytoplankton, often forming the dominant constituent of the nannoplankton (the fraction of less of 20 μm), because their dimensions rarely exceed 30 μm. They belong to the ambiguous group so-called 'phytoflagellates', and comprise a distinct assemblage of the Haptophyte algae, which bear ornamented calcified plates or coccoliths on the cell (or coccosphere) surface. The other particular characteristic, common to all Haptophyte algae, is the presence of a flagellum-like appendage, the haptonema. It has been estimated that the number of living species is almost 200 (Chrétiennot-Dinnet, 1990; Jordan & Kleijne, 1994), but there are many more described from fossils. The taxonomy of coccolithophorids is based mainly on the morphology of the coccoliths, but also the cell shape, coccosphere arrangement and the presence of different types of coccoliths on a single cell are taxonomic criteria (Faber & Preisig, 1994; Heimdal, 1997).

Coccolithophorids are often more abundant than other phytoplankton groups in warm, stratified and oligotrophic waters (Brand, 1994) and may occasionally bloom (Brown & Yoder, 1994). High cocolithophorids populations also occur in mature upwelled waters (Mitchell-Innes & Winter, 1987). Most living cocolithophorids inhabit tropical or subtropical waters, predominantly oceanic ones, although other species are rather neritic or found indifferently in both regions. Some particular species are regarded as 'shade' forms, because they have been found in the deep photic zone (Sournia, 1982).

Some oceanographic investigations have shown the importance of the group in the planktonic primary productivity and assimilation of CO_2 (Brand, 1994), and production of dimethylsulfide (DMS, a gas which enhances cloud formation in the atmosphere) (Heimdal et al., 1992; Malin et al., 1992; Brand, 1994; Brown & Yoder, 1994). Their role as oceanographic and paleontological indicators has also been stressed (Steinmetz, 1994; Takahashi, 1994).

Despite this importance, the studies on coccolithophorids in México are very few: only one has been made on floristics and systematics (in the Gulf of México by Gaarder & Hasle, 1971), and another on

distribution (in the Gulf of California by Hernández-Becerril, 1985, 1987). Possible causes for the lack of information on the group may be problems in collecting coccolithophorids, which involve sampling with large bottles or very fine-meshed plankton nets, preservation with a neutralized pH (close to 7 or even higher), and the analysis that requires certain experience in recognizing very small forms (many species may be easily ignored or misidentified in routine phytoplankton examinations). Ziveri et al. (1995) have investigated the annual cycle (1991–1992) of the coccolithophorids in the southern California Bigth, an area which is close to the present study area.

This is an attempt to gain more knowledge on this group in coasts of Baja California, México, which is more dedicated to the morphology, systematics and floristic of the coccolithophorids in that area.

Materials and methods

The study area is located between 24° and 31° N, and 112° and 117° W, along the coast of Baja California, Mexico. Transects perpendicular to the coast were established for sampling, dividing the area in three zones: North, Central and South (Fig. 1). Sampling was made during the cruise 'SIMSUP IX' (5–22 March, 1996). Bottle samples (4 l) were taken regularly at 5, 25 and 50 m (occasionally samples from 10 m were collected), from 16 fixed Stations (Fig. 1), and then preserved with neutralized (Sodium borate treated) formaldehyde solution (4% final concentration). A total of 32 samples were taken. Variables measured included temperature, salinity and dissolved oxygen, in vertical profiles. Typical ranges of temperature (°C) and salinity (psu) were, in the North zone: 14.6 and 33.6 in surface to 9.7 and 34.4 at 150 m, respectively; in the Central zone: 14.2 and 33.9 in surface to 11.2 and 34.7 at 15 m, respectively; and in the South zone: 15.5 and 34.3 in surface to 13.4 and 34.5 at 80 m, respectively.

The material was studied after sedimentation (more than 2 weeks), the concentrated sediment was then transfered to smaller bottles (450 ml) and analyzed: direct observations by light microscopy (LM) in fresh mounts; these were made by pippeting some drops from the bottom of the bottles and place them on to slides and then cover with coverslips. Observations by scanning electron microscopy (SEM) were also made, using material treated conventionally (filtered and rinsed with distilled water, mounted, air-dried and coated with gold). A Zeiss Axiolab light microscope (bright field, with attached camera) and a JEOL 1200 EX scanning electron microscope were used for our observations.

Terminology and systematics follow recent proposals (Kleijne, 1992; Jordan & Green, 1994; Siesser & Winter, 1994; Jordan et al., 1995; Kleijne et al., 1995; Heimdal, 1997; Young et al., 1997). The coccoliths of the family Rhabdosphaeraceae are referred to as rhabdoliths, following Kleijne (1992).

Results and observations

We identified 24 taxa (including species and varieties) of coccolithophorids, which are described and illustrated by LM and/or SEM; only four taxa were not illustrated. Some relevant references are annotated for each species and conspicuous synonyms are also provided. Table 1 provides the complete species list (arranged in alphabetical order).

Division: Haptophyta Cavalier-Smith
Class: Primnesiophyceae Hibberd
Order: Coccolithophorales Schiller
Family: Noëlaerhabdaceae Jerkovic
Genus: Emiliania Hay *et* Mohler
Emiliana huxleyi (Lohmann) Hay *et* Mohler var. *huxleyi*
(Fig. 2)

References: Okada & Honjo, 1973, pl. 1, Figures 1–3; Hallegraeff, 1984, p. 233. Figures 8–12; Heimdal, 1997, p. 793, pl. 5.

Description: Cells are spherical or subspherical (8–10 μm diameter). The coccoliths are of the placolith type, subcircular to broadly elliptical, covering the whole cell. The coccoliths are small (average between 3.5 μm long and 3.0 μm wide), slightly sunken in the center and present a reticulate grid at the margin of the coccoliths. The degree of calcification and corrosion in coccoliths varies in different specimens observed.

Distribution: Cosmopolitan and widely distributed in temperate and subtropical areas, including coastal waters. Very common and usually the dominant species in Baja California. Station and depth: N1 at 25, 50 m, N2 at 5, 25, 50 m, N3 at 5 m, C1 at 25 m, C2 at 25, 50 m, C4 at 5 m, C5 at 5, 25 m, C6 at 25, 50 m, S2

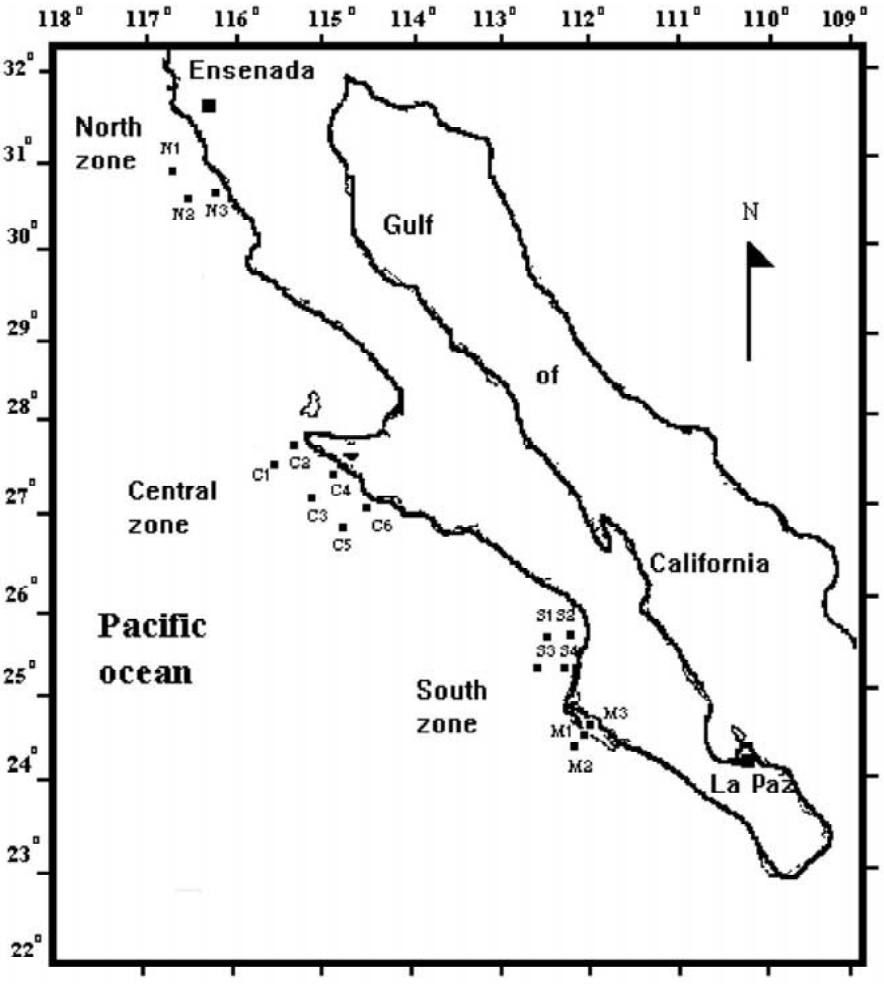


Figure 1. Map of the coasts of Baja California, showing the locations for sampling.

at 25 m, S3 at 5, 25 m, M1 at 5, 25 m, M2 at 5 m, M3 at 10 m.

Genus: Gephyrocapsa Kamptner

Gephyrocapsa oceanica Kamptner

(Figs 3–5)

References: Gaarder & Hasle, 1971, p. 533, Figures 6 d–f; Okada & McIntyre, 1977, p. 10, pl. 3 Figures 3–9; Reid, 1980, p. 154, pl. 1, Figure 6; Hallegraeff, 1984, p. 233, Figures 15–18; Heimdal, 1997, p. 796, pl. 5.

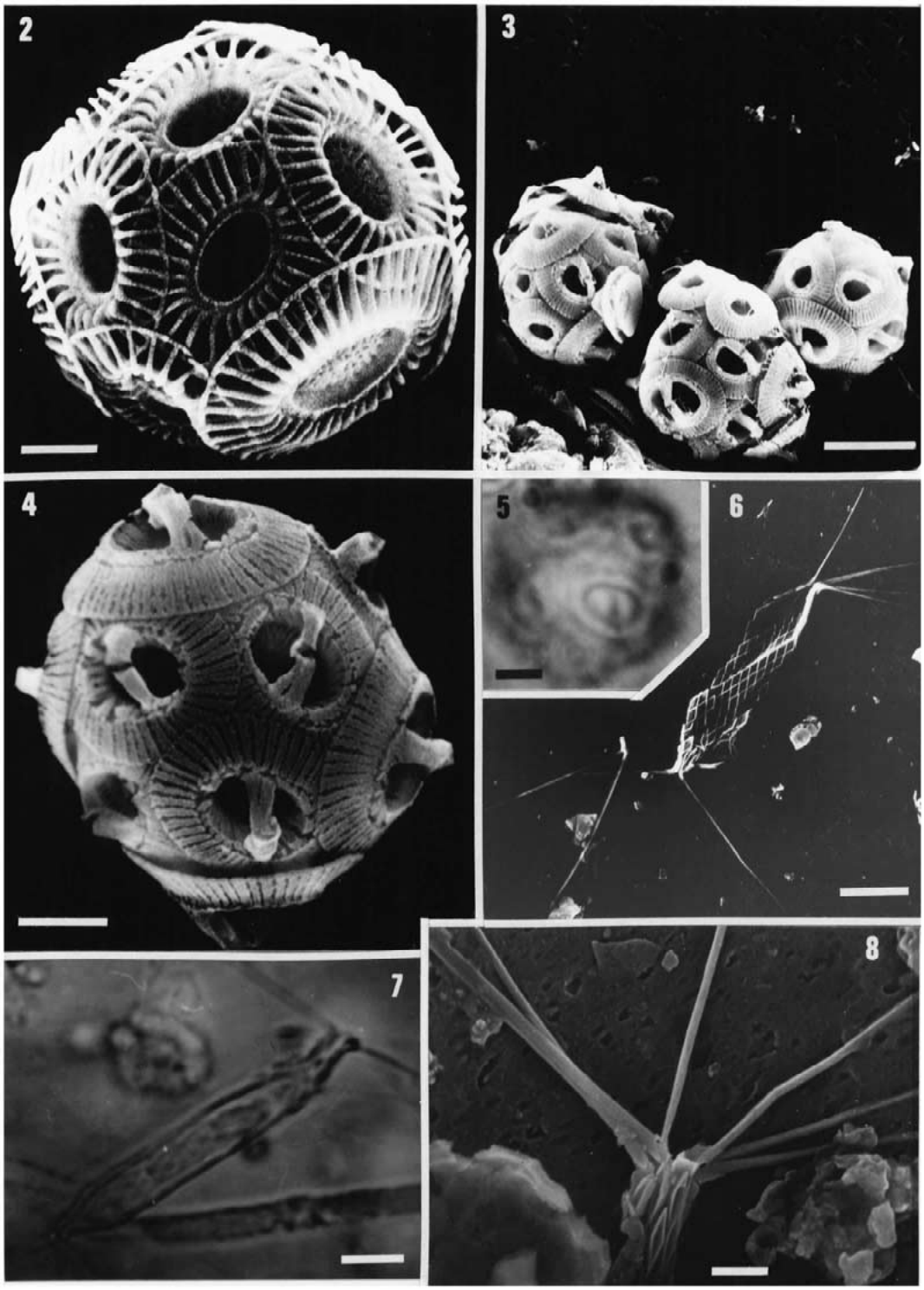
Description: Cells are spherical, with a diameter of 9–10 μm. The coccoliths (placoliths) are subcircular to elliptical, small to medium size (5.5 μm long, 3.5 μm wide, in average) with an elliptical central area, surrounded by a collar, and a bridge, showing considerable variations in morphology. The bridge is usually formed by two plates, oriented at approximately right angles to the longer axis of the coccolith. This species also shows a close reticulate grid at the margin of coccoliths.

Distribution: Widely distributed all over the world. Very common and dominant in Baja California. Station and depth: N1 at 25 m, N2 at 25, 50 m, N3 at 5 m, C1 at 25 m, C3 at 5 m, C4 at 5 m, S2 at 25 m, S3 at 5, 25 m, M1 at 5, 25 m, M2 at 5 m, M3 at 10 m.

Family: Calciosoleniaceae Kamptner

Genus: Anoplosolenia Deflandre

Anoplosolenia brasiliensis (Lohmann) Deflandre



Figures 2–8. Figure 2. *Emiliania huxleyi*, a whole coccosphere, SEM. Figures 3–5. *Gephyrocapsa oceanica*. Figure 3. Three complete cells, SEM. Figure 4. A whole coccosphere, SEM. Figure 5. One cell showing its coccoliths, LM. Figures 6–8. *Calciosolenia murrayi*. Figure 6. Complete cell, SEM. Figure 7. Another cell, LM. Figure 8. Detail of the apical part of a cell, showing long spines and scapholiths, SEM. Scale bars: 10 μm (Figs 6 and 7), 5 μm (Fig. 3), 2 μm (Figs 2, 4 and 8), 1 μm (Fig. 5).

Table 1. List of species of coccolithophorids form west coasts of Baja California

1.	*Acanthoica quattrospina* Lohmann (+) *
2.	*Algirosphaera oryza* Schlauder *
3.	*Algirosphaera robusta* (Lohmann) Norris
4.	*Anoplosolenia brasiliensis* (Lohmann) Deflandre *
5.	*Calciopappus rigidus* Heimdal (+)
6.	*Calciosolenia murrayi* Gran
7.	*Caneosphaera molischii* (Schiller) Gaarder (+)
8.	*Discophaera tubifera* (Murray *et* Blackman) Ostenfeld (+)
9.	*Emiliana huxleyi* (Lohmann) Hay *et* Mohler var. *huxleyi*
10.	*Florisphaera profunda* Okada *et* Honjo var. *profunda*
11.	*Florisphaera profunda* var. *elongata* Okada *et* McIntyre (+)
12.	*Gephyrocapsa oceanica* Kamptner
13.	*Helicosphaera carteri* (Wallich) Kamptner (+)
14.	*Helicosphaera hyalina* Gaarder (+)
15.	*Michaelsarsia adriaticus* (Schiller) Manton, Bremer *et* Oates (+)
16.	*Ophiaster formosus* Gran var. *formosus* emend. Gaarder (+) *
17.	*Ophiaster hydroideus* (Lohmann) Lohmann emend. Manton *et* Oates (+)
18.	*Rhabdosphaera claviger* Murray *et* Blackman var. *claviger*
19.	*Rhabdosphaera claviger* var. *stylifera* (Lohmann) Kleijne *et* Jordan (+)
20.	*Syracosphaera histrica* Kamptner (+) *
21.	*Syracosphaera pirus* Halldal *et* Markali (+) *
22.	*Syracosphaera pulchra* Lohmann
23.	*Umbilicosphaera sibogae* (Weber-Van Bosse) Gaarder var. *sibogae* (+)
24.	*Zygosphaera hellenica* Kamptner (+) *

(+) New records in the Mexican Pacific Ocean.
*Species not illustrated in this paper.

References: Gaarder & Hasle, 1971, p. 523, Figures 3 a–c; Manton & Oates, 1985, p. 466, pls. 1–2, Figures 1–7; Heimdal, 1997, p. 777, pl. 3.

Description: Cells are long and fusiform (70–80 μm total length, width: 4–8 μm). The coccoliths (scapholiths) are of a polygonal-rhombic shape, medium size 4–7 μm long, 0.2–0.5 μm wide.

Distribution: Recorded in the Atlantic, Pacific and Indian Oceans, Mediterranean Sea, Australian waters and the Gulf of Mexico. Very uncommon in Baja California. Station and depth: S2 at 25 m.

Genus: Calciosolenia Gran

Calciosolenia murrayi Gran

(Figs 6–8)

References: Schiller, 1930, p. 234, Figure 116; Gaarder & Hasle, 1971 p. 529, Figures 3 d, e; Heimdal, 1997, p. 781, pl. 4.

Description: Cells are long and cylindrical (34–38 μm without spines, total length: 65–75 μm, width: 8–10 μm). The cells are covered with scapholiths, small to medium size (2–3.5 μm long and 0.8–1.5 μm wide), which have a rhombic shape. In each extreme of the coccosphere, there are four or more spines (15–30 μm long). The cells show a neck-like constriction at the apical ends.

Distribution: Recorded in the Atlantic and Pacific Oceans, Mediterranean Sea, Australian waters and the Gulf of Mexico. Scarce in Baja California. Station and depth: N1 at 50 m, N2 at 5 m, N3 at 5 m, C4 at 5 m, C6 at 5 m, S2 at 25 m.

Family: Coccolithaceae Poche

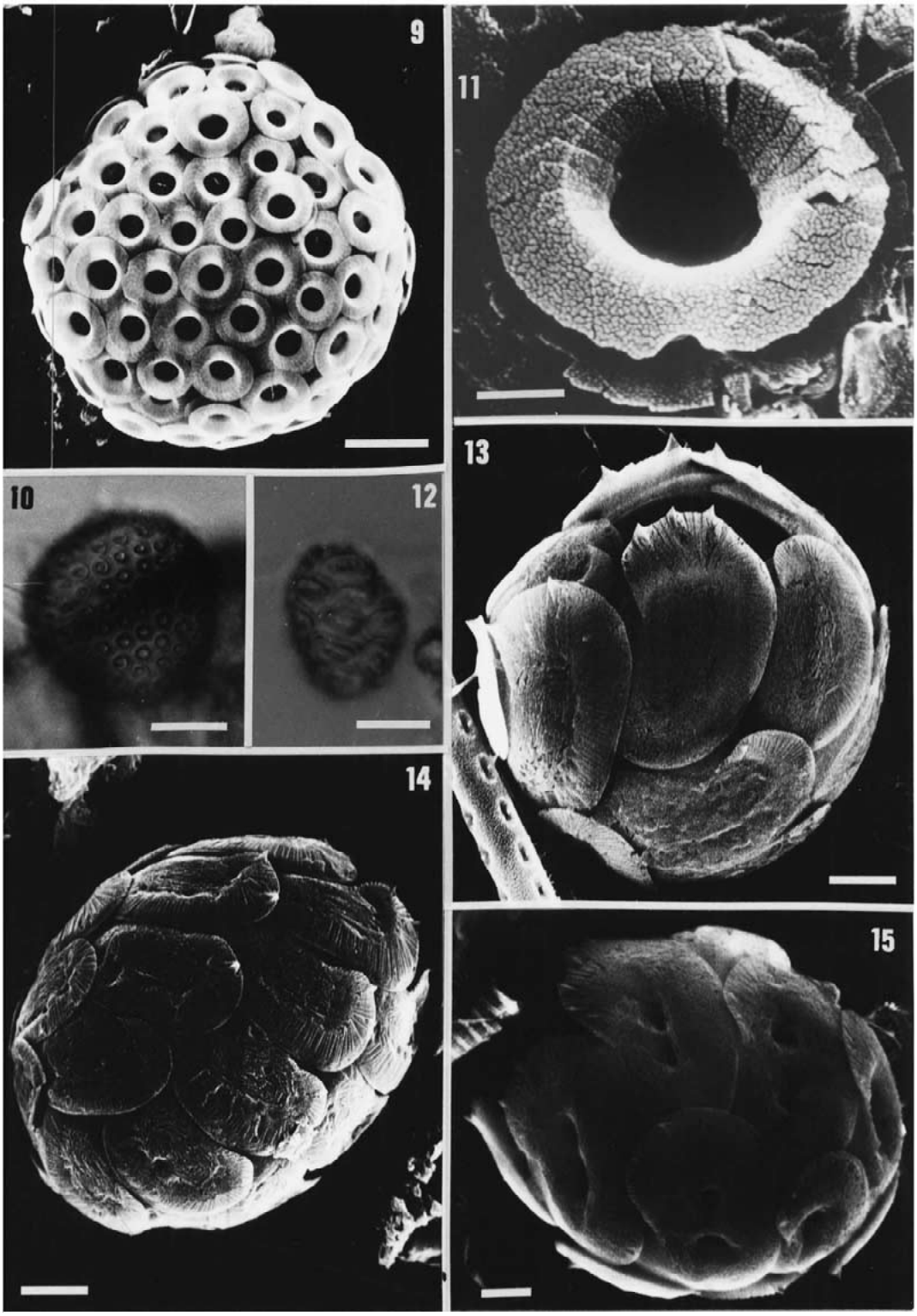
Genus: Umbilicosphaera Lohmann

Umbilicosphaera sibogae (Weber-Van Bosse) Gaarder var. *sibogae*

(Figs 9–11)

References: Gaarder, 1970, p. 122, Figures 8 c and 9 c, d; Okada & McIntyre, 1977, p. 13, pl. 4, Figure 2; Borsetti & Cati, 1976, p. 223, pl. 18, Figures 3 and 4; Reid, 1980, p. 155, pl. 2, Figures 1 and 2; Hallegraeff, 1984, p. 231, Figure 5 a; Heimdal, 1997, p. 815, pl. 7.

Description: Cells are spherical to oval, from 20 to 30 μm in diameter. The coccoliths are circular placo-



Figures 9–15. Figures 9–11. *Umbilicosphaera sibogae* var. *sibogae*. Figure 9. Coccosphere complete, SEM. Figure 10. One cell, LM. Figure 11. A single coccolith (placolith), SEM. Figures 12 and 15. *Helicosphaera carteri*. Figure 12. One cell, LM. Figure 15. Coccosphere complete, showing its helicoliths, SEM. Figures 13 and 14. *Helicosphaera hyalina*, two different coccospheres, SEM. Scale bars: 10 μm (Figs 10 and 12), 5 μm (Fig. 9), 2 μm (Figs 13–15), 1 μm (Fig. 11).

liths (3.5–4.5 μm in diameter) distributed all over the cell (50 and up to 100 in number). The placoliths have a large open central hole surrounded by a radius in a zig-zag pattern.

Distribution: Recorded in the Atlantic and Pacific Oceans, Mediterranean Sea and Australian waters. Fairly common in Baja California. Station and depth: N1 at 50 m, N2 at 5 m, N3 at 5 m, C3 at 5, 25 m, C4 at 5 m, S2 at 25 m.

Family: Helicosphaeraceae Black emend. Jafar *et* Martini

Genus: Helicosphaera Kamptner

Helicosphaera carteri (Wallich) Kamptner **(Figs 12 and 15)**

References: Gaarder, 1970, p. 114, Figures 2 e, f; Gaarder & Hasle, 1971, p. 533, Figures 9 a, b, e; Rampi & Bernhard, 1981, p. 53. pl. 23; Hallegraeff, 1984, p. 233, Figures 19, 20; Heimdal, 1997, p. 799, pl. 5

Description: Cells are ellipsoidal, 12–18 μm in diameter. The coccoliths (helicoliths) are elliptical and asymmetrical, covering the cell surface in an helicoidal pattern. The helicoliths are of medium size (6–9 μm long, 4–5 μm wide) and have two or more slender spines and radial striae on the margins of the coccoliths, whereas in the central part they have two large pores, varying in size, but always arranged in the same direction of the main axis.

Distribution: Recorded in the Atlantic and Pacific Oceans, also recorded in the Mediterranean Sea, Australiam waters, and the Gulf of Mexico. Common in Baja California. Station and depth: N1 at 50 m, N3 at 5 m.

Helicosphaera hyalina Gaarder

(Figs 13 and 14)

References: Gaarder, 1970, p. 113, Figures 1 a–g and 2 a–d; Gaarder & Hasle, 1971, p. 533, Figures 9 c, d, f; Rampi & Bernhard, 1981, p. 53, pl. 23; Heimdal, 1997, p. 799, pl. 5.

Description: Cells are ellipsoidal, 16 μm long and 12 μm wide. The cell surface is covered by elliptical helicoliths. The helicoliths (4.5–6 μm long, 3–4 μm wide) show radial striae on the margins and two or three spines at one extreme. Basically, it differs from *Helicosphaera carteri* by the absence of large pores in the central area of the coccoliths, for *H. hyalina* has a more homogeneous central area.

Distribution: Recorded in the Atlantic and Pacific Oceans, the Mediterranean Sea and the Gulf of Mexico. Common in Baja California. Station and depth: N3 at 5 m, C3 at 25 m, C6 at 5 m, S4 at 5 m.

Family: Rhabdosphaeraceae Haeckel

Genus: Acanthoica Lohmann emend. Schiller emend. Kleijne

Acanthoica quattrospina Lohmann

References: Schiller, 1930, p. 178, Figure 58; Kamptner, 1941, p. 76, pl. 1, Figures 5–8; Heimdal, 1997, p. 774, pl. 3.

Description: Cells are ellipsoidal to ovoid with 7–15 μm long and 5–9 μm wide. There are polar rhabdoliths at both poles with a large spine which is 10–15 μm long and ordinary rhabdoliths with 1.5–3 μm length.

Distribution: Norwegian Sea, North Atlantic, Pacific and Indian Oceans, Mediterranean Sea and Australian waters. Station and depth: S1 at 5 m.

Genus: Algirosphaera Schlauder emend. Norris

Algirosphaera oryza Schlauder

Reference: Heimdal 1997, p. 775, pl. 3.

Synonym: Anthosphaera oryza (Schlauder) Gaarder

Gaarder & Hasle, 1971, p. 523, Figures 4 a–e; Reid, 1980, p. 157, pl. 3, Figure 10.

Description: Cells are subspherical to ellipsoidal and slightly flattened and 10–15 μm in diameter. There are three to four larger, ovoid rhabdoliths in the central area, giving the cell a so-called 'coronate' profile.

Distribution: Atlantic, Pacific and Indian Oceans, Mediterranean Sea and Australian waters. Station and depth: N2 at 5 m, C4 at 5 m, M2 at 25 m, M3 at 10 m.

Algirosphaera robusta (Lohmann) Norris

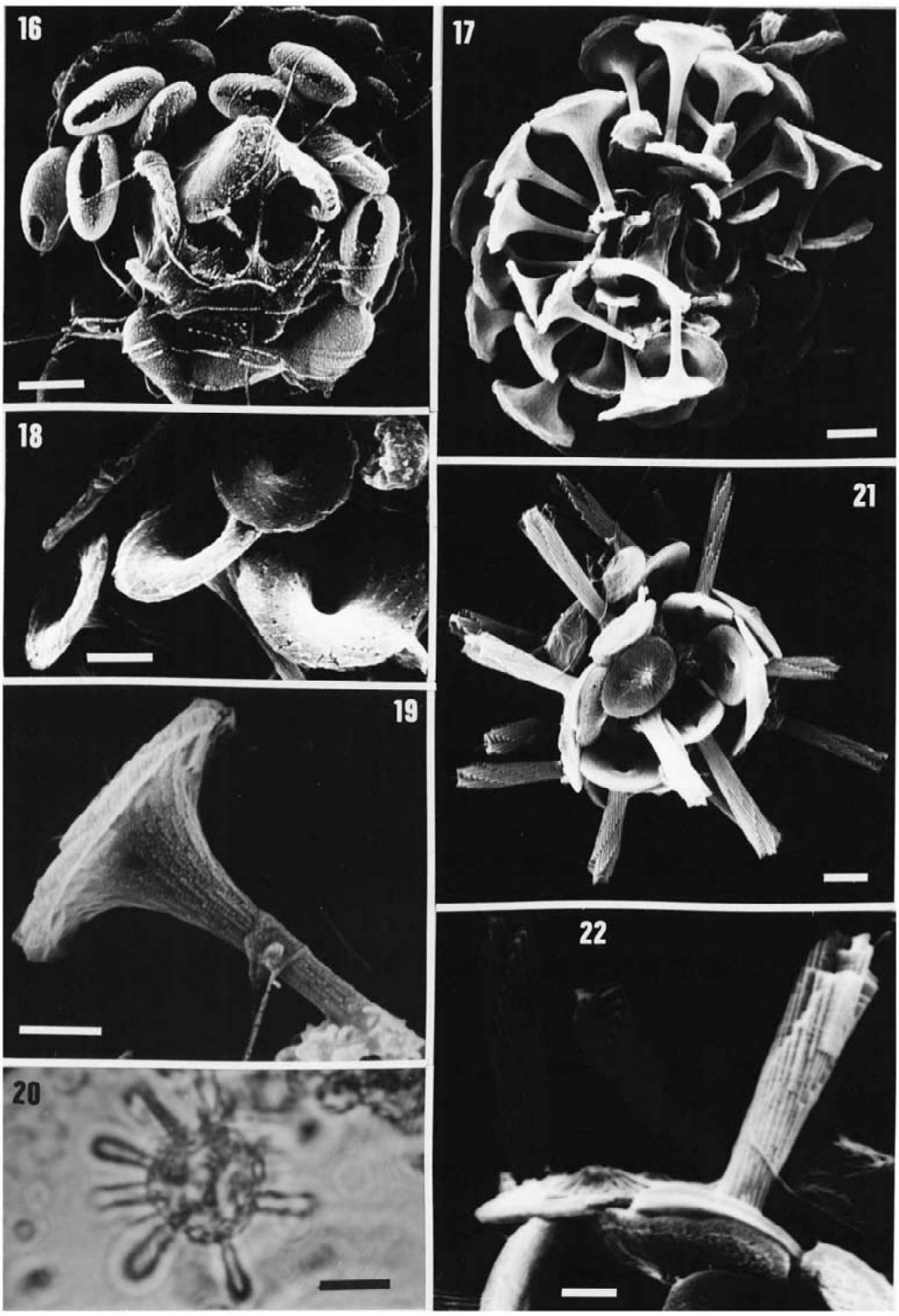
(Fig. 16)

References: Norris, 1984, p. 38; Heimdal, 1997, p. 775, pl. 3.

Synonym: Anthosphaera robusta (Lohmann) Kamptner

Kamptner, 1941, p. 86, pl. 9, Figures 91–94.

Description: The subspherical to ellipsoidal cells have a diameter of 10–16 μm. Dimorphic rhabdoliths are present, the stomatal ones are larger, forming a 'petaloid' shape 2–4 μm long and 2–3 μm wide, and the ordinary ones (sacculiform rhabdoliths), are 1–



Figures 16–22. Figure 16. *Algirosphaera robusta*, one cell in apical view, SEM. Figures 17–19. *Discosphaera tubifera*. Figure 17. One coccosphere, SEM. Figure 18. Detail of some coccoliths (cyrtoliths), SEM. Figure 19. A single cyrtolith, SEM. Figures 20–22. *Rhabdosphaera claviger* var. *claviger*. Figure 20. A complete cell, LM. Figure 21. A whole coccosphere, SEM. Figure 22. Individual coccoliths (rhabdoliths), SEM. Scale bars: 5 μm (Fig. 20), 2 μm (Figs 16, 17 and 21), 1 μm (Figs 18, 19 and 22).

2 μm long and 1.5–2 μm wide, with the same shape. Both types of coccoliths show an elongate central pore or depression, sometimes two.

Distribution: Worldwide. Scarce and uncommon in Baja California. Station and depth: C3 at 25 m.

Genus: Discophaera Haeckel

Discophaera tubifera (Murray *et* Blackman) Ostenfeld

(Figs 17–19)

References: Gaarder & Hasle, 1971, p. 533, Figures a–d; Jordan & Green, 1994, p. 155; Heimdal, 1997, p. 791, pl. 5.

Description: Spherical cells are 8–14 μm in diameter. The coccoliths have a salpingiform process (salpingiform rhabdoliths) and are trumpet-like (4–6 μm long and 2.5–4 μm wide), covering the whole cell. A base plate is present, composed of a marginal ring of elements connected to a solid central area. The number of coccoliths in the whole coccosphere may reach 30 or more.

Distribution: Worldwide. Fairly common in Baja California. Station and depth: S2 at 25 m, S4 at 5 m.

Genus: Rhabdosphaera Haeckel

Rhabdosphaera claviger Murray *et* Blackman var. *claviger*

(Figs 20–22)

References: Gaarder & Hasle, 1971, p. 536, Figure 11; Heimdal, 1997, p. 806, pl. 6.

Description: The spherical cell are 8–11 μm in diameter. The rhabdoliths have long processes and are 2.5–3.5 μm long and 1.5–3 μm wide at the basal plate. The claviform rhabdoliths have longitudinal striae and in the middle have a hole. The central area forms a prolongation (6–10 μm long), which is slightly thicker at the distal end and may have an apical papilla.

Distribution: Worldwide. Relatively common in Baja California. Station and depth: C6 at 5 m, S2 at 25 m, S4 at 5 m.

Rhabdosphaera claviger var. *stylifera* (Lohmann) Kleijne *et* Jordan

(Figs 23 and 24)

Reference: Kleijne & Jordan 1990, p. 13.

Synonym: Rhabdosphaera stylifer Lohmann Schiller, 1930, p. 250, Figure 129.

Description: Spherical cells are 8–10 μm in diameter. The rhabdoliths are 2.5–3.5 μm long and 1.5–3.5 μm wide. This taxa is very similar to *Rhabdosphaera claviger* var. *claviger*, but the main difference is the shape of the process. In var. *stylifer*, the process is not as thick at the end as in the nominal variety, as it has uniform width throughout.

Distribution: Worldwide. Common in Baja California. Station and depth: S2 at 25 m, S4 at 5 m.

Family: Syracosphaeraceae (Lohmann) Lemmermann

Genus: Calciopappus Gaarder *et* Ramsfjell emend. Manton *et* Oates

Calciopappus rigidus Heimdal

(Figs 28 and 29)

References: Heimdal & Gaarder, 1981, p. 42, pl. 2, Figures 5–8; Heimdal, 1997, p. 780.

Description: Cells are relatively large and ovoid to conical (10–12 μm length, 8–9 μm width). They have been described as having tetramorphic coccoliths, but our observation only include the ordinary coccoliths (caneoliths) and the particular coccolith type with a 'bayonet-like' distal part and split base with flattened appendage, which is attached to the proximal side of the whorl coccoliths (not seen); length of these coccoliths was 20–23 μm. Ordinary coccoliths are elliptical are relatively small (1.2–1.6 μm in length).

Distribution: Recorded in the Atlantic, Indian and Pacific Oceans, also in Mediterranean Sea. Scarce in Baja California. Station and depth: N1 at 50 m, N3 at 5 m.

Genus: Caneosphaera Gaarder

Caneosphaera molischii (Schiller) Gaarder

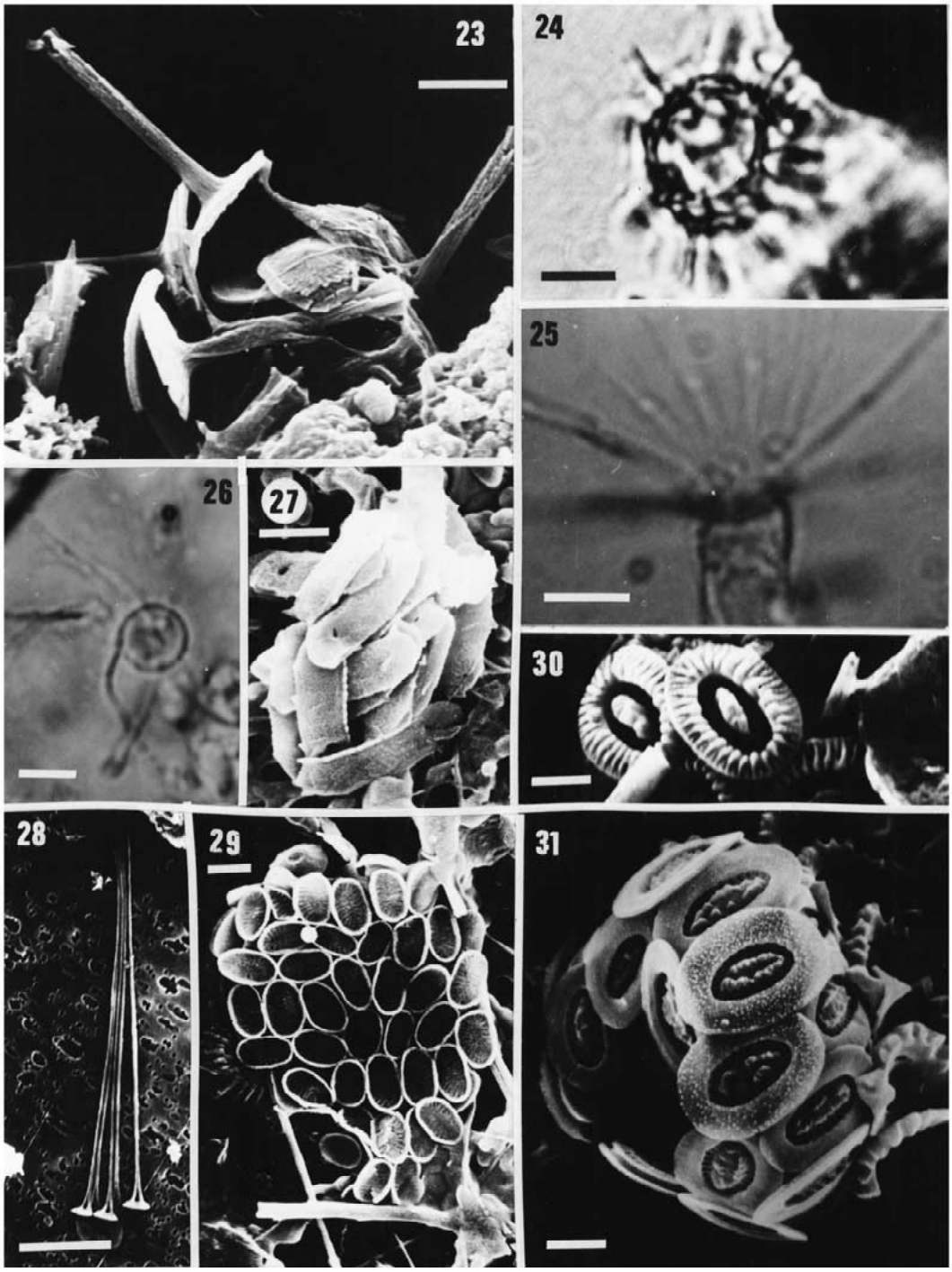
(Figs 30 and 31)

References: Gaarder & Heimdal, 1977, p. 66, pls. 7, 8, Figures 40–49; Heimdal & Gaarder, 1981, p. 44, pl. 3, Figures 10–16, Heimdal, 1997, p. 784, pl. 4.

Synonym: Syracosphaera corrugis Okada *et* McIntyre

Okada & McIntyre, 1977, p. 21, pl. 8, Figures 3 and 6.

Description: The spherical to subspherical cells are 5–10 μm in diameter. The coccoliths (caneoliths) are oval, and have radial elements in the margin and in the central area a little protuberance. They are 2.5–3 μm in length and 1.5–2 μm in width. The stomatal coccoliths are smaller and more circular than the or-



Figures 23–31. Figures 23 and 24. *Rhabdosphaera claviger* var. *stylifera*. Figure 23. Thin rhabdoliths, SEM. Figure 24. A complete cell, LM. Figure 25. *Michaelsarsia adriaticus*, Part of a cell, LM. Figures 26 and 27. *Ophiaster hydroideus*. Figure 26. A whole cell, LM. Figure 27. Detail of the processes, showing some links, SEM. Figures 28 and 29. *Calciopappus rigidus*. Figure 28. Some 'bayonet-like' coccoliths, SEM. Figure 29. A complete coccosphere with ordinary coccoliths Figures 30 and 31. *Caneosphaera molischii*. Figure 30. Coccoliths (caneoliths), SEM. Figure 31. A complete coccosphere, showing some smoother caneoliths, SEM. Scale bars: 10 μm (Fig. 25), 5 μm (Figs 24, 26 and 28), 2 μm (Fig. 23), 1 μm (Figs 27 and 29–31).

dinary ones with a high protrusion that can be rounded or flattened.

Distribution: Norwegian sea, Atlantic, Indian and Pacific Oceans. Fairly common in Baja California. Station and depth: S1 at 5 m, S2 at 25 m.

Genus: Michaelsarsia Gran emend. Manton Bremer *et* Oates

Michaelsarsia adriaticus (Schiller) Manton, Bremer *et* Oates

(Fig. 25)

References: Manton et al., 1984, p. 198, pls. 5–8.

Synonym: Haloppapus adriaticus Schiller

Schiller, 1930, p. 231, Figure 115; Gaarder & Hasle, 1971, p. 533, Figures 5 c, d; Hallegraeff, 1984, p. 239, Figure 38; Heimdal, 1997, p. 798, pl. 5.

Description: Cells are conical to oblong, 20–30 μm long and 8–15 μm wide, with several spine-like processes of up to 25 μm long in the apical part. These processes are formed by smaller parts linked together, the distal ones are thinner. Ordinary coccoliths are very small, arranged parallel to the main axis.

Distribution: Recorded in the Atlantic, Indian and Pacific Oceans, the Mediterranean Sea and Australian waters. Scarce in Baja California. Station and depth: N2 at 5 m, M3 at 10 m, S2 at 25 m, S3þat 25 m, S4 at 5 m.

Genus: Ophiaster Gran emend. Manton *et* Oates

Ophiaster formosus Gran var. *formosus* emend. Gaarder

References: Gaarder, 1967, p. 185, Figure 1-A; Manton & Oates, 1983, p. 460; Heimdal, 1997, p. 803.

Description: Cells are circular to slightly ovoid, 5–10 μm in diameter. There are various processes at the apical part of variable length (10–15 μm). Ordinary coccoliths are smaller.

Distribution: Indian Ocean and probably worldwide. Common in Baja California. Station and depth: N3 at 5 m, C4 at 5 m, S2 at 5, 25 m, M2 at 5 m, M3 at 10.

Ophiaster hydroideus (Lohmann) Lohmann emend. Manton *et* Oates

(Figs 26 and 27)

References: Schiller, 1930, p. 233, Figure 18; Gaarder, 1967, p. 184, Figure 1-B; Okada & McIntyre, 1977, p. 19, pl. 10, Figure 13; Manton & Oates, 1983, p. 444, pls. 1–4, Figures 1–25; Heimdal, 1997 p. 803, pl. 6.

Description: Cells are spherical or ovoid and have a diameter varying from 3 μm to 7 μm. Various processes (arms-like) with numerous links.

Distribution: Probably worldwide. Common in Baja California. Station and depth: N3 at 5 m, C4 at 5 m, S2 at 5 m, M2 at 5 m, M3 at 10 m.

Genus: Syracosphaera Lohmann

Syracosphaera histrica Kamptner

References: Kamptner, 1941, p. 84, pl. 6, Figures 65–68; Gaarder & Heimdal, 1977, p. 55, pl. 2, Figures 9–15; Okada & McIntyre, 1977, p. 22, pl. 8, Figure 12; Heimdal, 1997, p. 808, pl. 7.

Description: Ovoid to subspherical cells are 13–20 μm long and 10–14 μm wide. The stomatal coccoliths show a little spine, while the ordinary ones have no spine.

Distribution: Atlantic and Pacific Oceans, Mediterranean Sea. Scarce in Baja California. Station and depth: S2 at 25 m.

Syracosphaera pirus Halldal *et* Markali

References: Gaarder & Heimdal, 1977, p. 56, pl. 3, Figures 16–20; Okada & McIntyre, 1977, p. 26, pl. 9, Figures 10 and 11; Heimdal, 1997, p. 809, pl. 7.

Description: Pyriform to caudate and very long cells, which are 25–50 μm in length. The stomatal coccoliths have a central process.

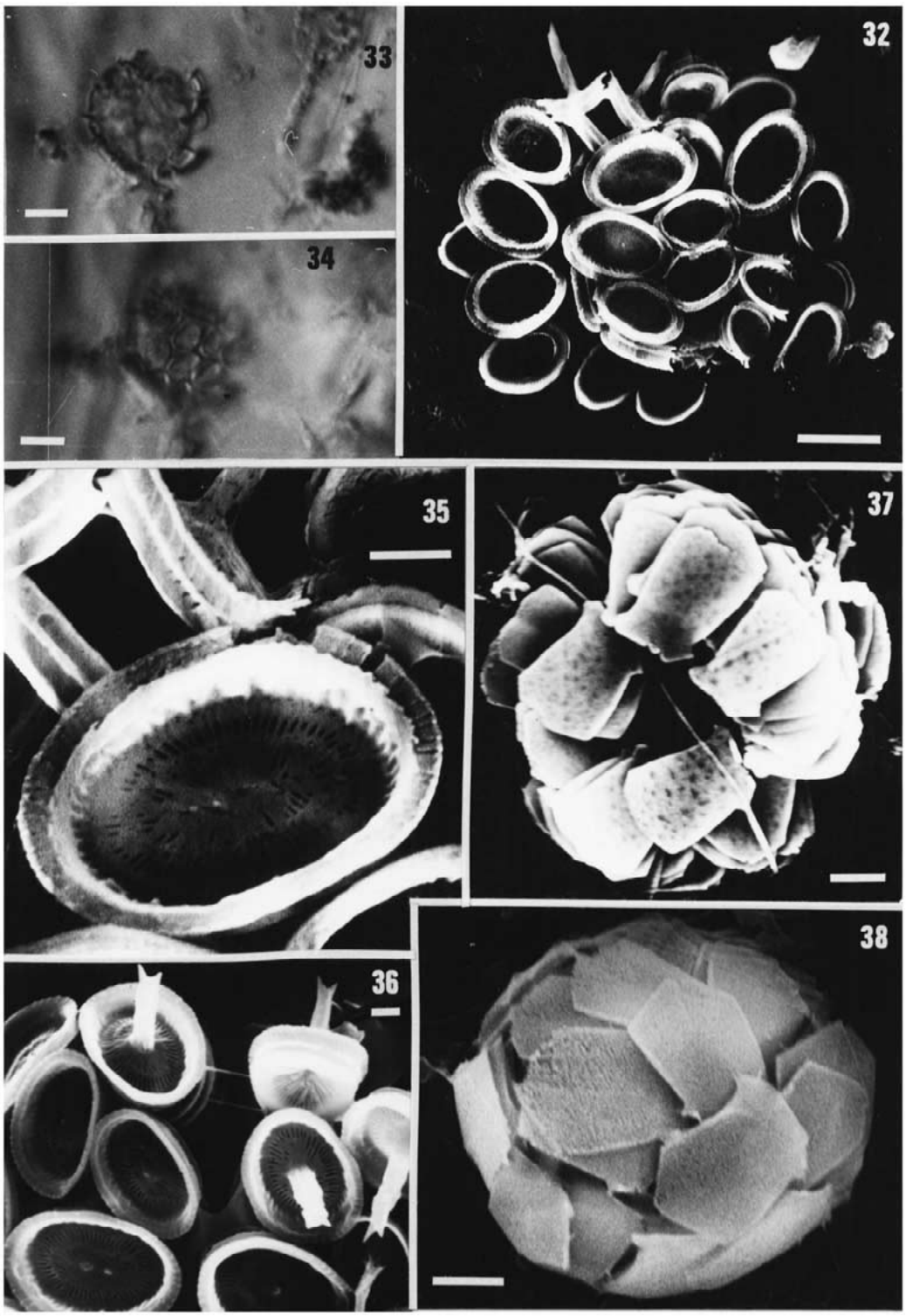
Distribution: In the Atlantic Ocean, Mediterranean and Caribbean Sea. Scarce in Baja California. Station and depth: S4 at 5 m.

Syracosphaera pulchra Lohmann

(Figs 32–36)

References: Gaarder & Heimdal, 1977, p. 55, pl. 1, Figures 1–8; Okada & McIntyre, 1977, p. 27, pl. 10, Figures 11 and 12; Hallegraeff, 1984, p. 239, Figure 49; Inouye & Pienaar, 1984, p. 207, Figures 1–15; Heimdal, 1997, p. 811, pl. 7.

Description: Pyriform to subspherical cells, which are 14–25 μm long and 10–14 μm wide. Stomatal coccoliths (caneoliths) have a short central process or spine. Ordinary coccoliths are oval, covering all the cell surface. The coccoliths are of medium size and measure 4–5 μm long and 2–3.5 μm wide. These coccoliths show, in the central area, radial intercon-



Figures 32–38. Figures 32–36. *Syracosphaera pulchra*. Figure 32. A coccosphere, SEM. Figures 33 and 34. Two different focus of a same cell, LM. Figure 35. Detail of a single caneolith, SEM. Figure 36. Stomatal (with spines) and ordinary coccoliths, SEM. Figure 37. *Florisphaera profunda* var. *profunda*, a whole coccosphere, SEM. Figure 38. *Florisphaera profunda* var. *elongata*, complete coccosphere, SEM. Scale bars: 5 μm (Figs 32–34), 1 μm (Figs 35–38).

necting elements at both extremes and in the margin have rectangular overlapping plates.

Distribution: Worldwide. Common in Baja California. Station and depth: N2 at 5 m, C4 at 5 m, S2 at 25 m, S4 at 5 m.

Family: Calyptrosphaeraceae Boudreaux *et* Hay

Genus: Zygosphaera Kamptner emend. Heimdal

Zygosphaera hellenica Kamptner

References: Reid, 1980, p. 166, pl. 8, Figures 1 and 2; Norris, 1985, p. 639, Figure 57; Kleijne, 1991, p. 69, pl. 18, Figures 3–5; Heimdal, 1997, p. 770.

Description: Subspherical cells are 9–15 μm in diameter. Ordinary coccoliths are elliptical laminoliths, whereas the stomatal coccoliths have pronounced grooves.

Distribution: In the Atlantic, Pacific and Indian Oceans, and the Mediterranean sea. Scarce in Baja California. Station and depth: C3 at 5 m, S4 at 25 m.

GENERA INCERTA SEDIS

Genus: Florisphaera Okada *et* Honjo

Florisphaera profunda Okada *et* Honjo var. *profunda*

(Fig. 37)

References: Okada & Honjo, 1973, p. 373, pl. 2, Figures 4 and 5; Okada & McIntyre, 1977, p. 36; Reid, 1980, p. 168, pl. 8, Figures 3 and 4; Heimdal, 1997, p. 794, pl. 5.

Description: Spherical cells (4–8 μm diameter) which have thin overlapping flat coccoliths. The coccoliths are nearly quadrangular (2.5 μm long and 1.5–2 μm wide), showing at the upper edge two projections and the lower edge is angled.

Distribution: Recorded in the Pacific and Atlantic Oceans. Scarce in Baja California. Station and depth: S2 at 25 m, S3 at 25 m.

Florisphaera profunda var. *elongata*. Okada *et* McIntyre

(Fig. 38)

References: Okada & Honjo, 1973, p. 374, pl. 1, Figure 6, pl. 2, Figure 6; Borsetti & Cati, 1976, p. 225, pl. 18, Figure 7; Okada & McIntyre, 1977, p. 36; Reid, 1980, p. 168, pl. 8, Figure 5.

Description: Subspherical cells which are 11–12 μm in diameter. This differs from the nominal variety by having rectangular coccoliths forming a rosette in apical view, 2.3 μm wide and 3.5 μm long, which develop a peak formed by two straight upper edges.

Distribution: In the North Atlantic and Pacific Oceans. Scarce in Baja California. Station and depth: S2 at 25 m, S3 at 25 m.

Discussion

This is the first systematic and floristic study of the coccolithophorids along the coast of Baja California. Twenty-four taxa (17 species and 5 nominal varieties, plus 2 other varieties) have been identified in the samples analyzed in this study. We report fifteen new records for the Mexican Pacific (Table 1), although the previous list of some coccolithophorids in the Gulf of California (Hernández-Becerril, 1985) did not include any descriptions nor illustrations. However, in the southern California Bight, Ziveri et al., (1995) have listed 63 taxa of the group, using different methodologies of collection and study.

The relative low number of taxa found in this study may, in part, be the result of the methods of collection and study of the samples. Fixation and treatment with distilled water may have caused the loss of delicate specimens, some of which could appear in fresh mounts (for LM), but not in the SEM. In continuing with studies of coccolithophorids, we are now using different protocols for collection and analysis of this group (e.g. filtration).

The coccolithophorid assemblages found here indicate a typical subtropical, coastal flora. The highest species diversity (e.g. number of species) was detected in more oceanic stations. Two species were the most abundant (relative abundance), dominant and widespread: *Emiliania huxleyi* and *Gephyrocapsa oceanica*. Some species were recorded only in the South zone, like *Anoplosolenia brasiliensis*, *Florisphaera profunda* (the nominal variety and var. *elongata*), *Syracosphaera histrica* and *S. pirus*, whereas *Calciopappus rigidus* was only found in the North zone.

No clear patterns can be discerned in the vertical distribution of the assemblages or individual species: the most abundant species *Emiliania huxleyi* and *Gephyrocapsa oceanica*, showed a somewhat evenly distributed pattern (at 5, 25 and 50 m). Some other species such as *Algirosphaera oryza*, *Helicosphaera hyalina* and *Syracosphaera pulchra* were more con-

centrated at 5 m, whereas *Discosphaera tubifera* and *Rhabdosphaera stylifera* were more abundant at 25 m.

However, we were able to find *Florisphaera profunda* (the nominal variety and var. *elongata*) at depths of 25 m, while most authors regard the two taxa as 'shade' forms, recorded only at 100 m or even deeper (Okada & Honjo, 1977; Reid 1980; Sournia, 1982). Upwelling events may be associated with this finding, or the species has a wider range of depths than previously reported. Forms not fully developed (deficient calcification, probably) were encountered in both *Emiliania huxleyi* and *Gephyrocapsa oceanica*, which may lead to misidentifications for the possible morphological intergrades between these two species.

Rhabdosphaera claviger and *R. stylifera* have been considered to be conspecific by several authors (e.g. Okada & McIntyre, 1977; Hallegraeff, 1984; Heimdal, 1997), who have found intergradation between these two species. However, no single coccosphere has been illustrated bearing distinct coccoliths: the thin ones of *R. stylifera*, and the broad club shaped *claviger* type, therefore we follow the proposition of Kleijne & Jordan, (1990) that both 'morphotypes' can be referred to as varieties.

In this paper, we consider that *Helicosphaera hyalina* can be separated from *H. carteri*, taking into account the shape of the cells and the morphology of the coccoliths: those of *H. carteri* showing two big pores in the central part, whereas *H. hyalina* has a homogeneous central part (Heimdal, 1997). Other opinions also exist, for *H. hyalina* has been referred to as a variety of *H. carteri* (Jordan & Young, 1990). In this study, we were unable to find intergrades in the pattern of coccoliths.

Another taxon, *Helicosphaera carteri* var. *wallichii* (Lohmann) Theodoridis (formerly, *H. wallichii* (Lohmann) Okada *et* McIntyre), appears to be a mere synonym of *H. carteri*, where coccoliths having only one big pore and those with two pores have been documented for a single coccosphere (e.g. Hallegraeff, 1984, Fig. 20). The species *Helicosphaera pavimentum* Okada *et* McIntyre seems to be very closely related to *H. hyalina* (Okada & McIntyre, 1977), and we think that it might be considered as a synonym of the former one. Our Figure 14 strongly resembles *H. pavimentum*.

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