Coastal Coccolithophores (Guest Ed. R.W. Jordan)
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Coccolithophorid assemblages off the coast of Guam

Susumu Konno
Marine Works Japan Ltd., 3-54-1 Oppamahigashi, Yokosuka 237-0063, Japan

Christopher S. Lobban
Division of Natural Sciences, University of Guam, Mangilao, Guam 96923, USA

Misaki Ishizawa, Richard W. Jordan*
Department of Earth & Environmental Sciences, Faculty of Science, Yamagata University, 1-4-12 Kojirakawa-machi, Yamagata 990-8560, Japan;
*sh081@kdw.kj.yamagata-u.ac.jp

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Abstract Surface and subsurface water samples were collected off the western coast of Guam during late September 2008. All samples were dominated by diatoms, with dinoflagellates often being the second most important group. Coccolithophorid absolute abundance (<3.0 x 10^3 cells/L) and species diversity (generally <10 spp./site) were very low, but included both hetero- and holococcolithophorid taxa, as well as the rarely reported coastal species, *Cruciplacolithus neohelis*. Net samples were also collected off the eastern coast of Guam, as well as from Apra Harbor on the western side, during March 2013; however, the coccolithophorid diversity was much lower on the eastern side of the island, perhaps due to the high particulate load from river outflow. Despite this, some live specimens were observed and photographed. This is the first report of coccolithophorids from Guam, and although the assemblages showed some similarities with those from other subtropical/tropical Pacific islands, surprisingly few cells of *Emiliania huxleyi* were encountered, while *Gephyrocapsa oceanica* and *Umbellosphaera tenuis* were only seen as loose coccoliths.

Keywords Coastal assemblages, coccolithophorids, Guam, Pacific Ocean

1. Introduction

Reports of coccolithophorid assemblages in subtropical/tropical coastal waters are still relatively rare, with possibly the best records being from the Pacific (Marshall, 1933; West, 1969; Okada & Honjo, 1975; Hallegraeff, 1984; Inouye, 1988; Konno & Jordan, 2006). In general, western Pacific coastal waters are dominated by *Gephyrocapsa oceanica* (Okada & Honjo, 1975; Konno & Jordan, 2006), which is known to form large blooms in Australian and Japanese bays (Blackburn & Cresswell, 1993; Okabe, 1997; Kai et al., 1999; Ogura & Sato, 2001; Ikeda, 2007); however, coccolithophorid assemblages in coastal areas usually have low diversity, and the relative abundances of certain species either increase (e.g. *Florisphaera profunda*, *Calcidiscus leptoporus* and *Umbilicosphaera sibogae*) or decrease (e.g. *Gephyrocapsa oceanica* and *Helicosphaera* spp.) with increasing water-depth (as demonstrated by Okada, 1992 and Konno & Jordan, 2006).

2. Study area

The general oceanic circulation around the Territory of Guam (centred around 13º28'N, 144°45'E) is controlled by the North Equatorial Current, which flows northwest at about 0.1–0.2ms^{-1} (Uda, 1970). The circulation is temporally and spatially variable, however, with island-generated eddies also playing a major role in the dispersal and return of marine plankton, eggs and larvae (Wolanski et al., 2003 and references therein). The island has a warm climate all year round (24–27°C), with a humid rainy season during August–October. There are a number of coral reefs, principally on the western side, at Apra Harbor, Agat and Cocos Lagoon – the main areas sampled in this study (see Fig. 1). Unlike the Republic of Palau (Konno & Jordan, 2006), Guam has numerous small rivers, many of which flow into the various bays around the island.

This investigation of the coccolithophorid assemblages off the coast of Guam is part of an ongoing international project to survey the microalgae associated with coral reef ecosystems in Micronesia, particularly diatoms in farmer fish algal turfs (e.g. Navarro & Lobban, 2009; Lobban et al., 2009–2018, 2012; Lobban & Jordan, 2010; Lobban, 2015).

3. Material and methods

3.1 Sampling sites

Water and net samples were collected off the western and eastern coasts of Guam during September 2008 and March 2013, respectively. The sampling sites were accessed in several ways. The surface samples from Gabgab Beach (28 September, 2008) and some of those from off the

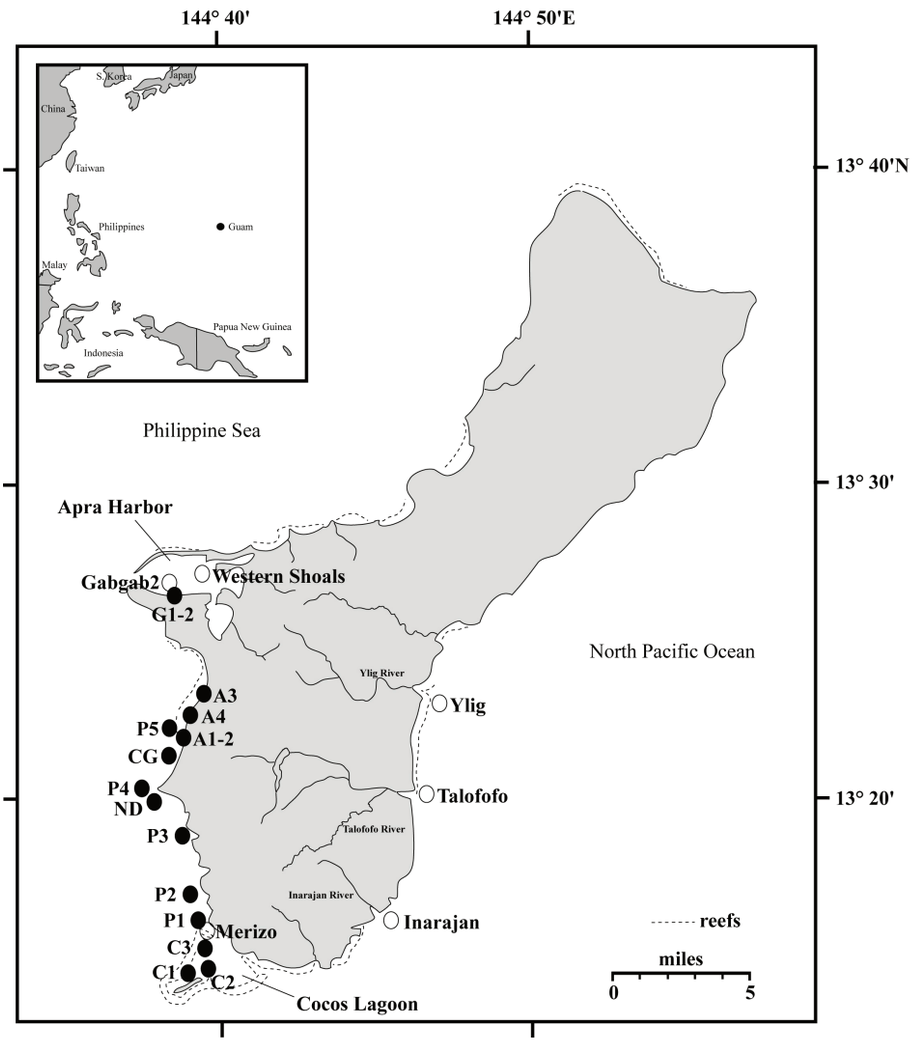


Figure 1: Map of Guam, showing locations of the sampling sites. Filled circles = 2008, open circles = 2013. A – Agat, C – Cocos Lagoon (Coco), CG – Coral Gardens (Dive 2), G – Gabgab Beach (Gab), ND – Nathan's Dent (Dive 1), P – plankton (PLA). Inset indicates the position of Guam in the western Pacific Ocean

Agat coast (27 September, 2008) were obtained simply by swimming out to the reef or for a short distance offshore. The other surface samples and plankton-net samples along the western and eastern coasts were acquired using a small chartered boat – *Bank-it* – on 26 September, 2008 and 9 March, 2013, respectively, as well as in Apra Harbor on 12 March, 2013. SK obtained subsurface samples by scuba diving at two locations off the Agat coast – Nathan's Dent and Coral Gardens – using the Micronesian Divers' Association dive boat *Sun Chaser* on 27 September, 2008. A GPS meter, together with a field map, was used to pinpoint the exact locations of most of the sampling sites. The main sampling areas are described in more detail below.

Gabgab Beach

This beach is a popular diving and snorkeling area, located in the southern part of the Apra Harbor Naval Reservation (US military base), which requires authorisation to enter. Samples from this area are identified by the prefix 'G'. In 2008, we used the divers' entrance point to access the nearshore reef, which is several metres deep, while the deeper reef area is situated about 100m from the shore, and is perhaps 5–10m deep. Samples G1 and G2 were collected from the nearshore and deeper reef areas, respectively. In 2013, we entered the harbour using the chartered boat *Bank-it*, and obtained water and net samples from Gabgab 2 and Western Shoals.

Agat

Coral reefs are present almost continuously along the western coast of Guam, between Apra Harbor and Cocos Lagoon, but are easily accessible near Agat Marina. The samples collected in 2008 from this area are identified by the prefix 'A'. To the south of the marina lies Nimitz Beach Park, from where Samples A1 and A2 were collected. These waters are shallow, with beds of seaweed. To the north, between the marina and Bangi Island, is a narrow stretch of beach and shallow water sparsely populated by seagrasses, from where Sample A3 was taken, north of the outflow of the small Chaligan River. Sample A4 was collected from the ramp at the marina, which is protected from strong waves by a concrete breakwater.

Both of the dive sites visited in 2008 are for beginners, being relatively shallow. Coral Gardens, varying in depth from 2–15m, is situated inside a coral reef on the south side of Anae Island, while Nathan's Dent is slightly deeper

(9–24m), and named after a V-shaped cut in the reef near Facpi Point.

Off the western coast

In 2008, on the return journey from Cocos Lagoon to Agat Marina, a number of water and plankton-net samples were taken in deeper offshore waters, in part to collect pelagic zooplankton and phytoplankton (thus samples from this area are identified by the prefix 'P'). Sample P1 was obtained from just outside Mamaon Channel (the entrance to Cocos Lagoon), off the Bingot coast and to the south of Bile Bay. Sample P2 was taken outside Toguan Bay, to the south of Mamatgun Point, P3 from just outside Cetti Bay and P4 from the seaward side of Facpi Island, off Facpi Point. The last sample, P5, was collected on the seaward side of the Agat Marina breakwater.

Cocos Lagoon

This area is relatively shallow (only a few metres deep) and characterised by seaweed and seagrasses growing on coralline sands. Samples collected in 2008 from this area are identified by the letter 'C'. Samples C1 and C2 were taken from two points off the coast of Cocos Island, while C3 was obtained closer to Mamaon Channel.

Off the eastern coast

In 2013, on the return journey from Ylig to Cocos Lagoon, a number of plankton-net samples were taken in deeper offshore waters – off Ylig, Talofofo Bay, Inarajan and Merizo.

Other sites

Although not included in Figure 1, water samples were also collected in 2008 from four further locations, by wading out close to the shore on the eastern side of Guam: Achang (a mangrove reserve area); Asgon Point by Salaglula (Saluglula) Pool; north of Talofofo Bay, between Ypan (Ipan) Point and Asanite Point; and at Ypan (Ipan) Beach. The shallow inlets in south-eastern Guam tend to have high turbidities and low water transparencies, however, due to the reddish, clayey soil-laden river-waters entering the sea at these points.

3.2 Physicochemical data

In 2008, physicochemical data were acquired, using a multiple water-quality monitor (U-22, Horiba Co., Ltd.), from all sites, except the two dive sites (Nathan's Dent and Coral Gardens) and G2, the offshore site at Gabgab Beach. In addition to these data, Table 1 shows the sampling date, sampling depth and approximate depth to the seabed at each sampling site.

In 2013, the physicochemical data were acquired, using a multisensor water-quality device (AAQ1183, Alec Electronics Co., Ltd.), from all sites, to a water-depth of about 20m. Only the data for the surface-waters are shown in Table 2.

	south ←															north →
	C1	**C2**	**C3**	**P1**	**P2**	**P3**	**ND**	**P4**	**CG**	**A2**	**P5**	**A1**	**A4**	**A3**	**G2**	**G1**
Sampling date (summer 2008)	26/9	26/9	26/9	26/9	26/9	26/9	27/9	26/9	27/9	27/9	26/9	27/9	27/9	27/9	28/9	28/9
Depth to seabed (m)	1.5	1.8	1.75	27.4	9.1	15.2	24.4	32.3	14.4	<1.0	7.0	<1.0	<1.0	<1.0	<5.0	<1.0
Measuring depth (m)	1.0	1.0	1.1	1.1	0.9	0.8	n/a	1.4	n/a	0.8	1.3	1.0	1.2	1.3	n/a	1.1
Temperature (°C)	29.76	30.30	30.85	30.46	30.01	29.92	n/a	29.98	n/a	32.29	30.08	32.22	32.80	32.07	n/a	29.98
Salinity (psu)	36.0	36.0	36.0	36.2	36.3	36.2	n/a	36.3	n/a	36.3	36.2	35.8	35.8	36.2	n/a	35.7
pH	8.13	8.27	8.36	8.29	8.23	8.22	n/a	8.24	n/a	8.32	8.21	8.25	8.42	8.47	n/a	8.18
Conductivity (S/m)	5.43	5.43	5.43	5.46	5.47	5.47	n/a	5.47	n/a	5.48	5.46	5.40	5.40	5.47	n/a	5.39
Turbidity (NTU)	3.3	0.5	2.3	0.0	0.0	0.0	n/a	0.0	n/a	4.4	0.0	11.2	0.9	0.8	n/a	3.6
Dissolved oxygen (mg/L)	6.82	7.50	9.53	7.98	6.87	6.75	n/a	6.89	n/a	8.53	6.90	7.99	9.32	10.21	n/a	6.40

Table 1: Sampling date, approximate depth to the seabed and physicochemical data recorded at each of the sampling sites visited in 2008. The samples and measurements were obtained from surface-waters unless otherwise stated. n/a – data not available

	Ylig	Talofofo	Inarajan	Merizo	Gabgab2	Western Shoals
Sampling date (spring 2013)	9/3	9/3	9/3	9/3	12/3	12/3
Measuring depth (m)	1.0	1.1	1.0	1.1	1.0	1.0
Temperature (°C)	28.03	28.15	27.99	28.11	28.11	28.15
Salinity (psu)	34.8	34.74	34.84	34.91	34.74	34.77
chlorophyll *a* (µg/L)	0.172	0.239	0.097	0.313	0.164	0.544
Conductivity (mS/cm)	56.02	56.01	55.99	56.22	55.97	56.06
Turbidity (FTU)	4.33	0.91	0.25	0.88	0.16	1.08
Dissolved oxygen (mg/L)	6.61	6.82	6.76	6.95	6.77	6.68

Table 2: Sampling date and physicochemical data recorded at each of the sampling sites visited in 2013

3.3 Sample collection and preparation

Surface and subsurface water samples were collected using 1- or 2-L plastic water-bottles. In 2008, subsurface samples were obtained from 15m (Nathan's Dent) and 10m (Coral Gardens) deep by scuba diving (SK), using the methodology outlined in Konno & Jordan (2006). At the Microscopy Teaching and Research Laboratory on the University of Guam campus, 2L of seawater from each sampling site were filtered through Millipore HA-type polycarbonate filters (47mm diameter, 0.45μm porosity), using an Eyela Aspirator A-3S (Tokyo Rikakikai Co., Ltd.) filtration apparatus. The filters were air dried and then stored in plastic PetriSlides. Later, at Yamagata University, a 3 x 3mm portion of each filter was cut out and mounted onto an aluminium stub, coated with platinum/palladium in an Eiko IB-3 ion sputter-coater, and examined in a Hitachi S-2250N scanning electron microscope (SEM). Photographs were taken with the camera attachment, using Fuji Neopan 120 SS black and white film. Species were identified using the pictorial guide of Young et al. (2003) and the classification scheme of Jordan et al. (2004). Raw counts were converted to cells/L using the equation given in Jordan & Winter (2000).

In 2013, net samples were collected using a Nytal Swiss HD10 plankton net (with 10μm openings), but no water-bottle samples were taken, so only relative abundances were calculated (except at Western Shoals, where no counts were made). At the Microscopy Teaching and Research Laboratory on the University of Guam campus, aliquots of the net samples were pipetted onto glass slides, and observed with differential interference contrast illumination under a Nikon 80i light microscope (LM), with digital images being taken using a DS-Fil camera system and an L2 controller (Nikon Instruments, Redmond, WA, USA). SEM stubs with a 6 x 6mm filter portion mounted on them were examined in a JEOL JSM-6510LV SEM, and digital images were taken using the built-in camera system.

All of the samples, digital images and negatives obtained in this study are curated in the Department of Earth & Environmental Sciences, Faculty of Science, Yamagata University.

4. Results

4.1 Physicochemical data

In September 2008, the seawater around Guam was relatively warm (29–32°C), salty (35–36 psu) and only slightly turbid near the shore (Table 1). In contrast, in March 2013, the seawater around Guam was cooler (28°C), less salty (34–35 psu) and a little more turbid offshore.

4.2 Microplankton abundance

From the 2008 data, it is clear that diatoms were the most dominant group on the filters, ranging from about 1.8 x 10^4–1.2 x 10^5 cells/L, and representing 92–99% of the total mineralised microplankton. In contrast, dinoflagellates and coccolithophorids had relatively low abundances – 358–1672 cells/L and 0–2687 cells/L, respectively. Diatom abundances were generally higher in shallower waters, while coccolithophorids were more numerous at the offshore sites.

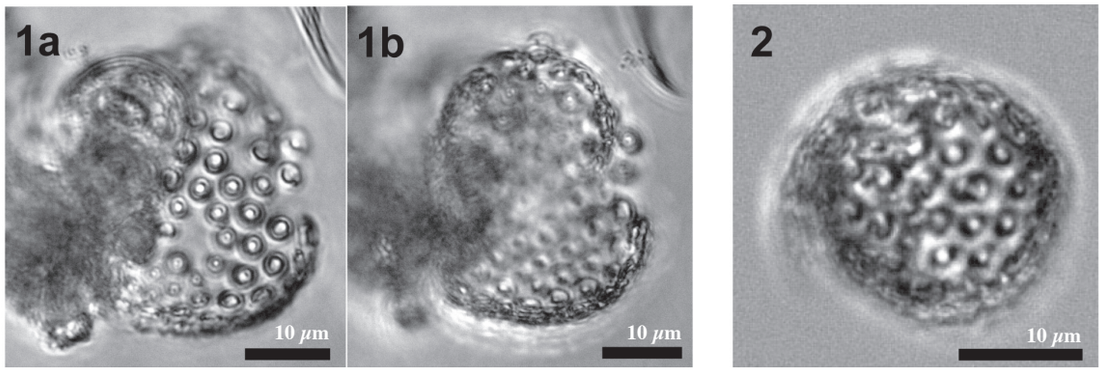
Only relative abundances were calculated for 2013 (data not shown here), with diatoms representing 89–94% and dinoflagellates 0.3–2.6% of the total mineralised microplankton. Coccolithophorids were only observed on the filter from Western Shoals, although live cells were rare at most sampling sites (Plate 1).

4.3 Coccolithophorid diversity

In 2008, cells of 20 coccolithophorid species (and loose coccoliths of a further three species) were identified, representing a wide variety of families, including four holococcolithophorid species (Table 5); however, no more than 10 species were found at each site, and no species were found at all sites. In 2013, living cells of four species

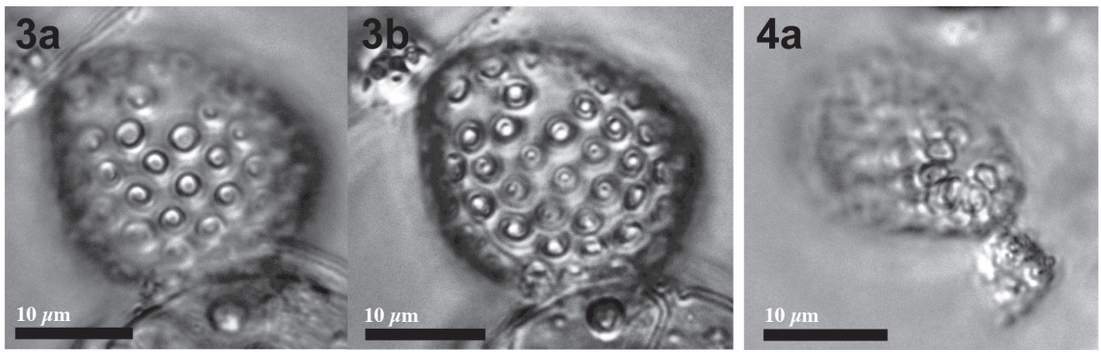
Plate 1

LM images of 'live' coccolithophorids collected by plankton net, March 2013



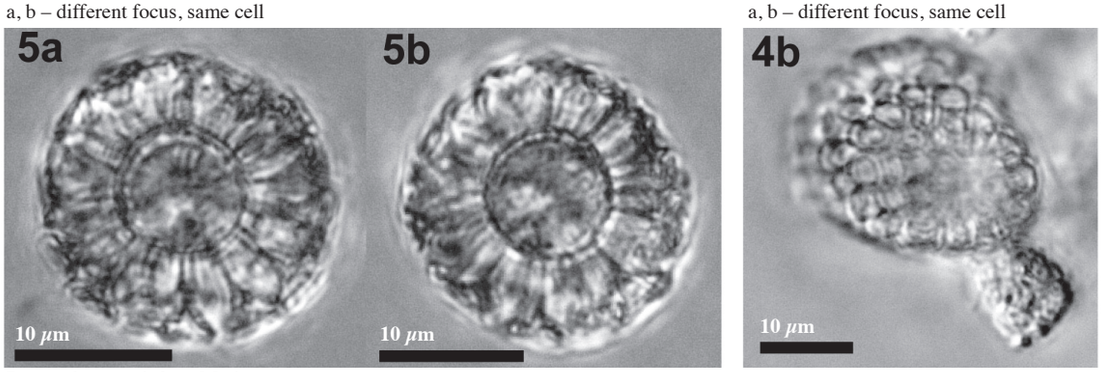
Umbilicosphaera sibogae, Merizo
a, b – different focus, same cell

U. sibogae, Gabgab

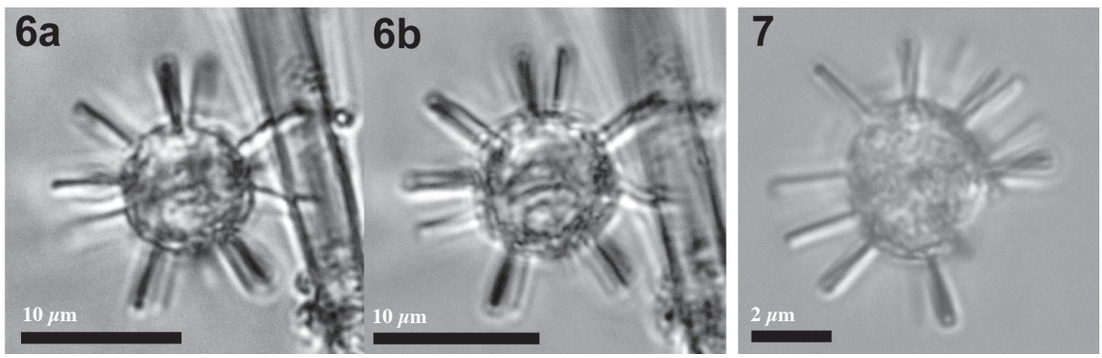


U. sibogae, Talofofo
a, b – different focus, same cell

Syracosphaera? sp., Talofofo
a, b – different focus, same cell



Discosphaera tubifera, Merizo
a, b – different focus, same cell



Rhabdosphaera clavigera, Talofofo
a, b – different focus, same cell

R. clavigera, Ylig

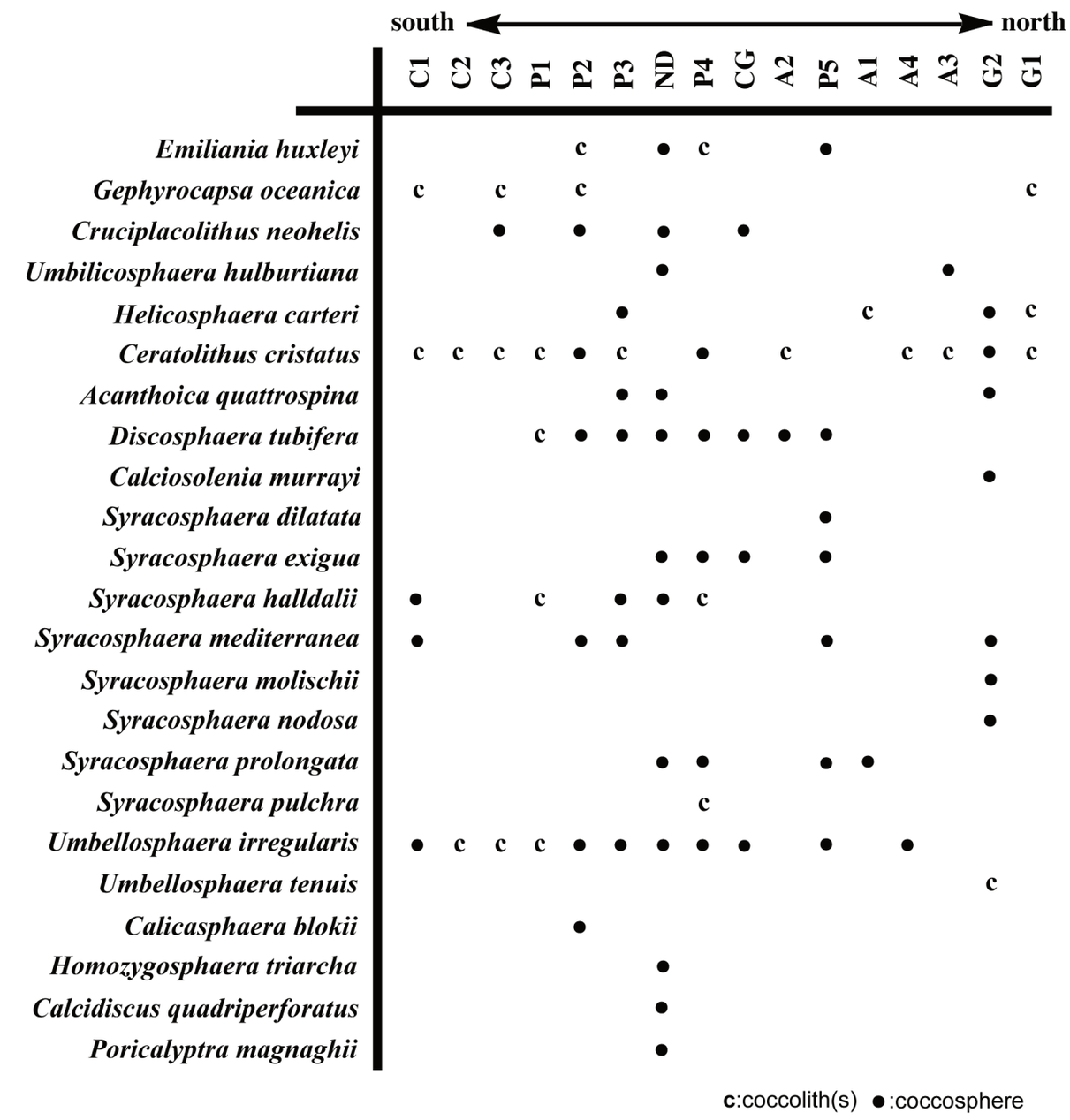


Table 5: Presence/absence of coccolithophorid species at each sampling site

were observed in the LM, from various sites (Plate 1), while four species (*Discosphaera tubifera*, *Syracosphaera mediterranea* and *Syracolithus catilliferus* as cells, and *U. sibogae* as loose coccoliths) were encountered in the SEM, but only from Western Shoals (images not shown).

5. Notes on occolithophorid taxon distributions

Emiliania huxleyi (Lohmann) Hay & Mohler var. *huxleyi*

Pl. 2, figs 1–2

The two specimens found at Nathan's Dent, and another one outside Agat Marina (P5), are clearly assignable to *E. huxleyi* var. *huxleyi* (= morphotype A) because they possess robust distal shield elements and curved central-area elements.

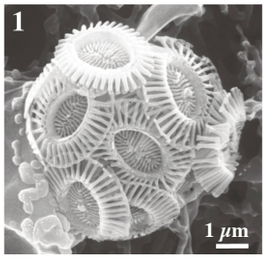
Gephyrocapsa oceanica Kamptner

Pl. 2, fig. 3

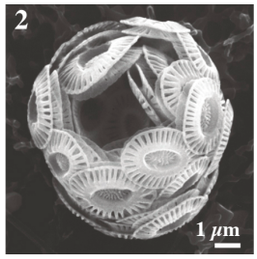
Surprisingly, only an isolated coccolith was found in this study, with the specimen at Gabgab Beach (G1) bearing a collar, but lacking its bridge.

Plate 2

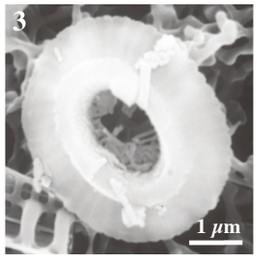
SEM images, September 2008



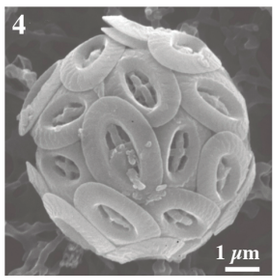
Emiliania huxleyi var. *huxleyi* coccospheres
Nathan's Dent

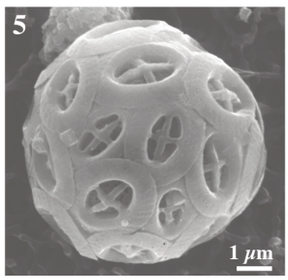


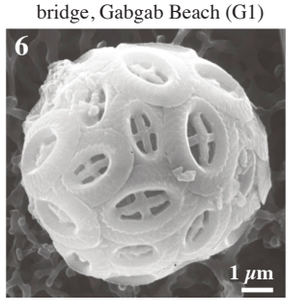
Nathan's Dent



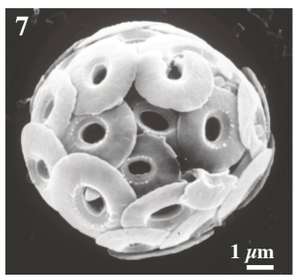
Gephyrocapsa oceanica
coccolith, distal view, broken bridge, Gabgab Beach (G1)

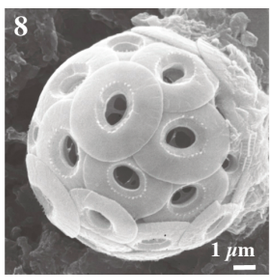


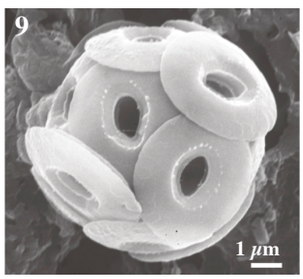




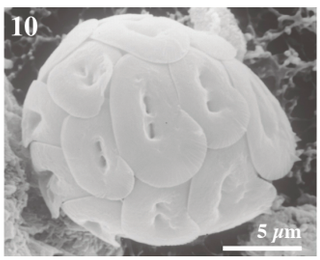
Cruciplacolithus neohelis coccospheres
Cocos Lagoon — Mamatgun Point — Coral Gardens

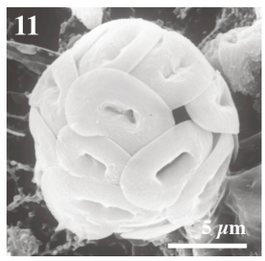


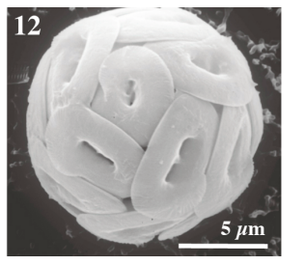




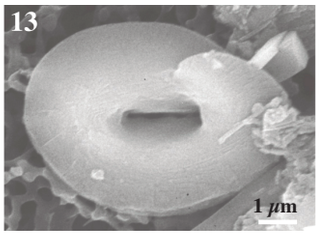
Umbilicosphaera hulburtiana coccospheres
Nathan's Dent — Agat (A3) — Agat (A3)

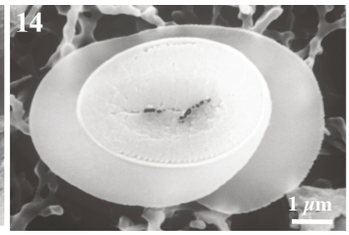


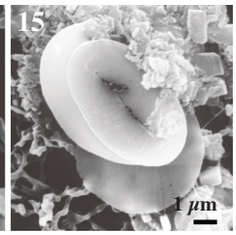




Helicosphaera carteri coccospheres, all Gabgab Beach (G2)







Helicosphaera carteri coccoliths
distal view, Gabgab Beach (G1) — proximal views, both Gabgab Beach (G2)

Cruciplacolithus neohelis (McIntyre & Bé) Reinhardt

Pl. 2, figs 4–6

Five specimens of this rarely encountered species have been found to date, one at Cocos Lagoon (close to Mamaon Channel, C3), one at Mamatgun Point (P2), two at Nathan's Dent and one at Coral Gardens.

Umbilicosphaera hulburtiana Gaarder

Pl. 2, figs 7–9

Two specimens were found along the coast of Agat (A3), and another specimen was collected from Nathan's Dent. It should be noted that one of the coccospheres (Pl. 2, fig. 9) has fewer, and much larger, coccoliths than the other two coccospheres. As shown by Konno & Jordan (2006), the coccolith morphology of this species can be highly variable.

Umbilicosphaera sibogae (Weber-van Bosse) Gaarder

Pl. 1, figs 1–3

Three specimens were found in the net samples from Merizo, Gabgab and Talofofo, collected in March 2013, as well as some loose coccoliths on the Western Shoals filter.

Helicosphaera carteri (Wallich) Kamptner

Pl. 2, figs 10–15

Most of the coccospheres were found at Gabgab Beach (G2), but with one specimen from outside Cetti Bay (P3), and isolated coccoliths from Gabgab Beach (G1 and G2) and at Agat (A1) (not illustrated). A tintinnid from Gabgab Beach (G1) was seen bearing two *H. carteri* coccoliths on its lorica (not illustrated). Similarly to the record from Palau (Konno & Jordan, 2006), the coccolith morphology of the Guam specimens is highly variable. Some coccoliths have two slits aligned in a row (see Pl. 2, fig. 10), others appear to have one long slit, whilst several coccoliths have slits oriented at different angles or parallel to each other (see Pl. 2, figs 12–15).

A single specimen of *S. catilliferus* (Kamptner) Deflandre was observed on the Western Shoals filter (not illustrated). This taxon is now considered to be a synonym of *H. carteri* (Jordan et al., 2004).

Ceratolithus cristatus Kamptner

Pl. 3, figs 1–2

At most of the sites (C1, C3, P3, A2–4 and G1), only isolated HET coccoliths of the *coccolithomorpha* type were encountered; however, collapsed coccospheres were found at three sites (P2, P4 and Nathan's Dent), including a specimen from Facpi Island (P4) that possessed a single hoop coccolith (see Pl. 3, fig. 2; this was not included in the count in Table 4).

Acanthoica quattrospina Lohmann

Pl. 3, figs 3–5

Five coccospheres were found in this study, two outside Cetti Bay (P3), one at Nathan's Dent and two at Gabgab Beach (G2).

Discosphaera tubifera (Murray & Blackman) Ostenfeld

Pl. 1, fig. 5; Pl. 3, figs 6–8

Coccospheres were found at Mamatgun Point (P2), outside Cetti Bay (P3), at Nathan's Dent, Facpi Island (P4), Coral Gardens, Agat (A2) and outside Agat Marina (P5) in September 2008, as well as in a net sample from Merizo and on a filter from Western Shoals, taken in March 2013.

Rhabdosphaera clavigera Murray & Blackman

Pl. 1, figs 6, 7

Two coccospheres were found in net samples from Talofofo and Ylig in March 2013.

Calciosolenia murrayi Gran

Pl. 3, figs 9–10

Only a single specimen was encountered at Gabgab Beach (G2).

Syracosphaera dilatata Jordan et al.

Pl. 4, fig. 1

Only a single specimen was recorded, from outside Agat Marina (P5). Both body and circumflagellar coccoliths can be seen.

Syracosphaera exigua Okada & McIntyre

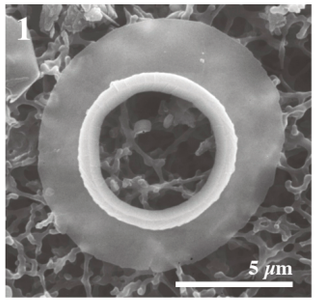
Pl. 4, figs 2–5

Seven specimens were found in this study, four from Nathan's Dent, one from Coral Gardens, one from outside Agat Marina (P5) and another from Facpi Island (P4), which was not included in the count (Table 4). All specimens exhibit body and exothecal coccoliths.

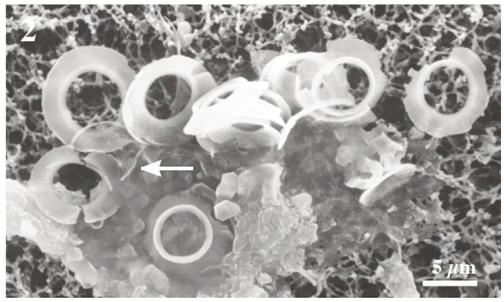
Syracosphaera halldalii Gaarder *ex* Jordan & Green

Pl. 4, figs 6–7

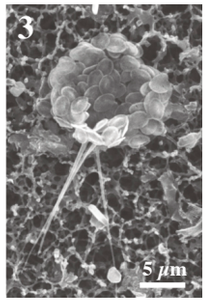
Plate 3



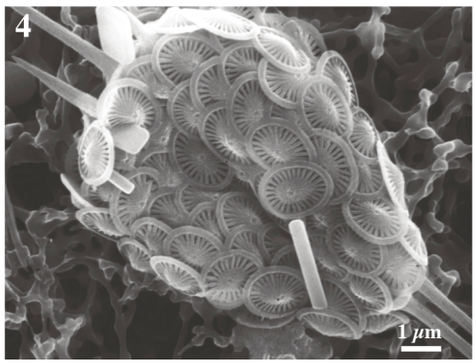
Ceratolithus cristatus HET *coccolithomorpha* type coccolith, distal view
Cocos Lagoon (C1)



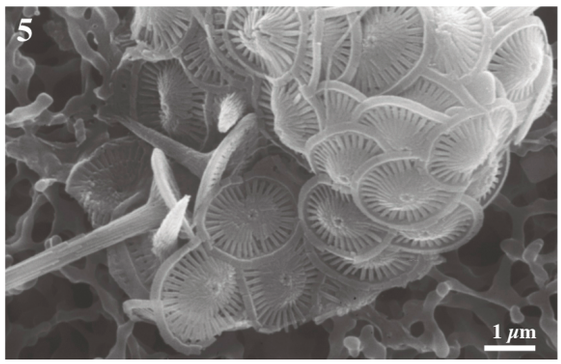
collapsed coccosphere, note ring coccolith (arrowed)
Facpi Island (F4)



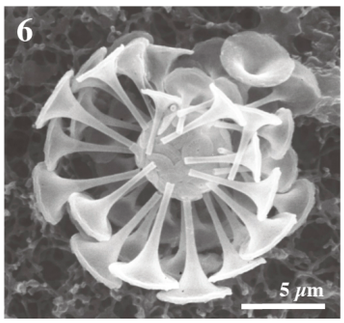
Acanthoica quattrospina coccosphere
Cetti Bay (P3)

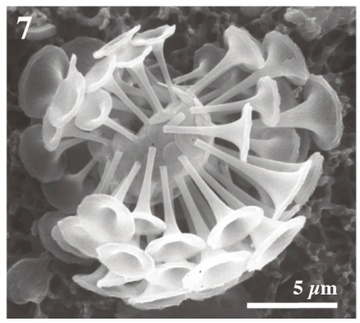


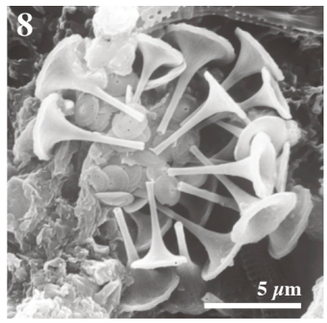
Acanthoica quattrospina coccospheres
Nathan's Dent



Close-up of coccoliths
Gabgab Beach (G2)



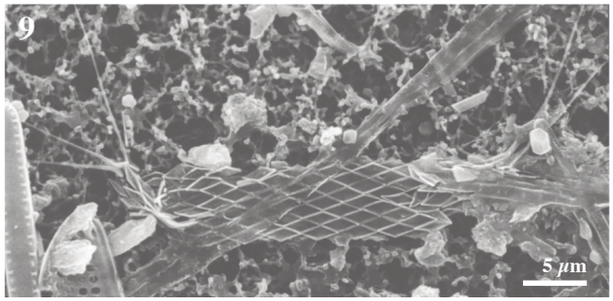




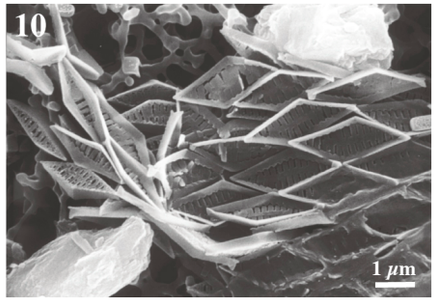
Discosphaera tubifera coccospheres
Cetti Bay (P3)

Nathan's Dent

Agat (A2)



Calciosolenia murrayi coccosphere
Gabgab Beach (G2)



Close-up of coccoliths, same specimen

	south ← C1	C2	C3	P1	P2	P3	ND	P4	CG	A2	P5	A1	A4	A3	G2	G1 → north
Emiliania huxleyi	0	0	0	0	0	0	119	0	0	0	60	0	0	0	0	0
Cruciplacolithus neohelis	0	0	60	0	60	0	119	0	60	0	0	0	0	0	0	0
Umbilicosphaera hulburtiana	0	0	0	0	0	0	60	0	0	0	0	0	0	119	0	0
Helicosphaera carteri	0	0	0	0	0	60	0	0	0	0	0	0	0	0	537	0
Ceratolithus cristatus	0	0	0	0	60	0	0	0	0	0	0	0	0	0	60	0
Acanthoica quattrospina	0	0	0	0	0	119	60	0	0	0	0	0	0	0	119	0
Discosphaera tubifera	0	0	0	0	60	179	358	239	119	60	60	0	0	0	0	0
Calciosolenia murrayi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60	0
Syracosphaera dilatata	0	0	0	0	0	0	0	0	0	0	60	0	0	0	0	0
Syracosphaera exigua	0	0	0	0	0	0	239	0	60	0	60	0	0	0	0	0
Syracosphaera halldalii	60	0	0	0	0	179	299	0	0	0	0	0	0	0	0	0
Syracosphaera mediterranea	60	0	0	0	119	60	0	0	0	0	60	0	0	0	179	0
Syracosphaera molischii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60	0
Syracosphaera nodosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60	0
Syracosphaera prolongata	0	0	0	0	0	0	60	60	0	0	119	0	0	0	0	0
Umbellosphaera irregularis	60	0	0	0	119	60	1075	0	60	0	179	0	60	0	0	0
Calicasphaera blokii	0	0	0	0	60	0	0	0	0	0	0	0	0	0	0	0
Homozygosphaera triarcha	0	0	0	0	0	0	119	0	0	0	0	0	0	0	0	0
Calcidiscus quadriperforatus	0	0	0	0	0	0	60	0	0	0	0	0	0	0	0	0
Poricalyptra magnaghii	0	0	0	0	0	0	119	0	0	0	0	0	0	0	0	0

Table 4: Absolute abundances (in cells/L) of the coccolithophorid species at each sampling site

Five specimens were found at Nathan's Dent, three outside Cetti Bay (P3) and one in Cocos Lagoon (C1). Both of the illustrated specimens exhibit body and circumflagellar coccoliths.

Syracosphaera mediterranea Lohmann

Pl. 5, figs 1–3

Eight specimens were found in this study, one at Cocos Lagoon (C1), two at Mamatgun Point (P2), one outside Cetti Bay (P3), one outside Agat Marina (P5) and three at Gabgab Beach (G2), in September 2008. In addition, another specimen was observed from Western Shoals in March 2013 (not illustrated).

Syracosphaera molischii Schiller

Pl. 4, fig. 8

The specimen found at Gabgab Beach (G2) appears to belong to type 3 (Young et al., 2003).

Syracosphaera nodosa Kamptner

Pl. 4, fig. 9

One specimen from Gabgab Beach (G2) was encountered, which exhibits body, circumflagellar and exothecal coccoliths.

Syracosphaera prolongata Gran *ex* Lohmann

Pl. 4, figs 10–12

Five coccospheres were encountered in this study, one from Nathan's Dent, one from Facpi Island (P4), two from outside Agat Marina (P5) and one from Agat (A1, which was not included in the count), as well as loose coccoliths from Nathan's Dent.

Syracosphaera pulchra Lohmann

not illustrated

Loose coccolith observed from Facpi Island (P4).

Syracosphaera sp.

Pl. 1, fig. 4

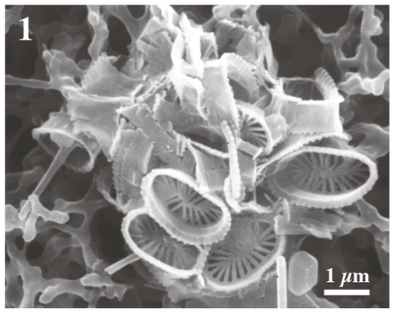
A single coccosphere was found in a net sample from Talofofo in March 2013.

Umbellosphaera irregularis Paasche

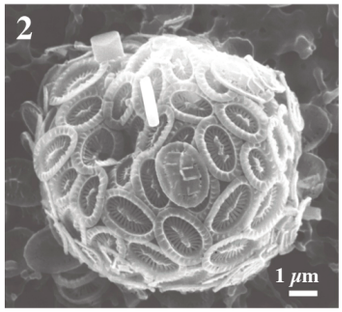
Pl. 5, figs 4–8

Twenty-nine coccospheres were found in total, 18 from Nathan's Dent, two from Mamatgun Point (P2), three from outside Agat Marina and the rest from Cocos Lagoon (C1), outside Cetti Bay (P3), Coral Gardens and Agat (A4), plus two from Facpi Island (P4) that were not included in the

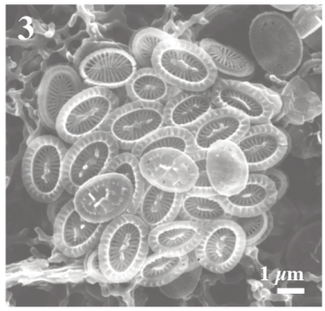
Plate 4



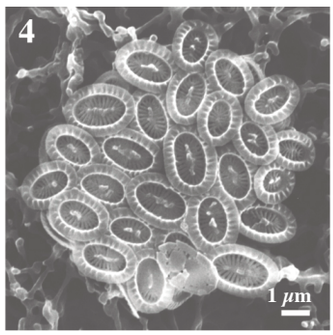
Syracosphaera dilatata collapsed coccosphere
outside Agat Marina (P5)



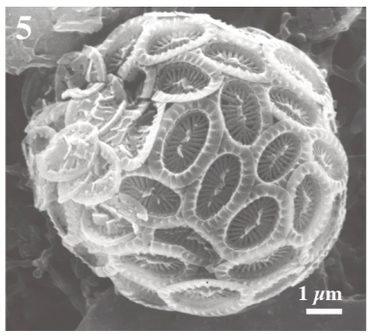
Syracosphaera exigua coccosphere
Nathan's Dent



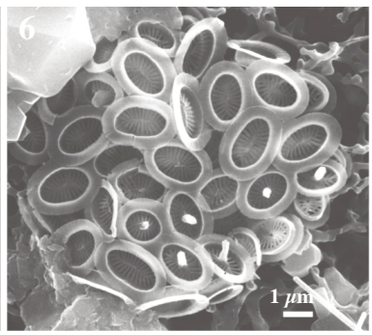
S. exigua collapsed coccosphere
Nathan's Dent



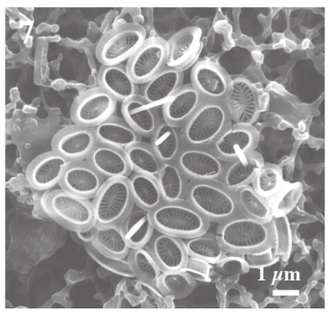
S. exigua collapsed coccosphere
Nathan's Dent



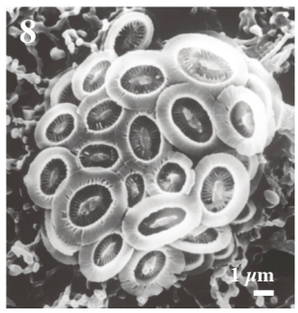
S. exigua coccosphere
Facpi Island (P4)



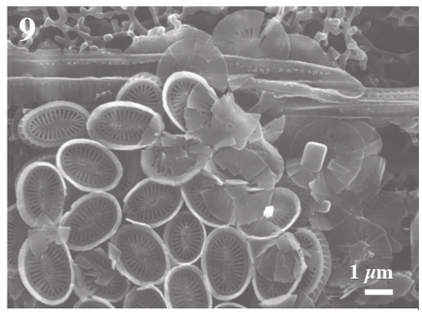
Syraco. halldalii collapsed coccosphere
Nathan's Dent



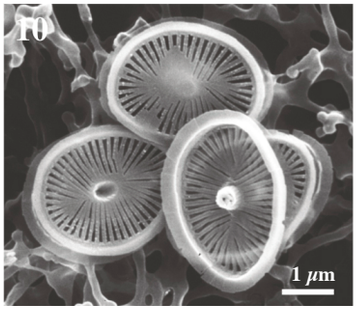
S. halldalii collapsed coccosphere
Nathan's Dent



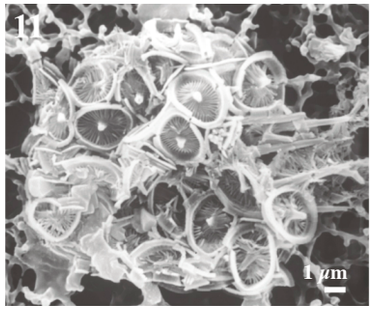
Syracosphaera molischii
collapsed coccosphere
Gabgab Beach (G2)



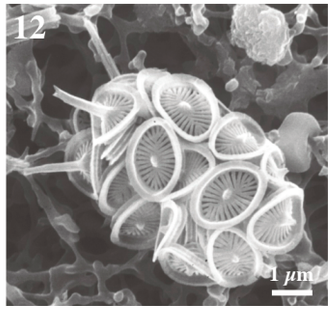
Syracosphaera nodosa collapsed coccosphere
Gabgab Beach (G2)



Syracosphaera prolongata coccoliths
Nathan's Dent

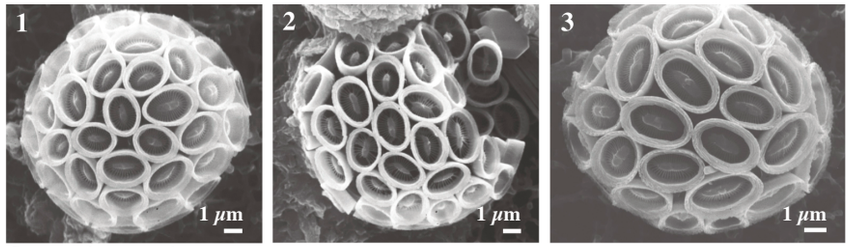


collapsed coccosphere
Facpi Island (P4)



coccosphere
Agat (A1)

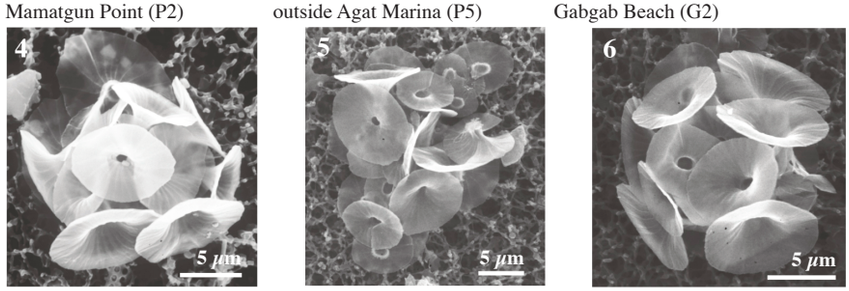
Plate 5



Coronosphaera mediterranea coccosphere
Mamatgun Point (P2)

partially collapsed coccosphere outside Agat Marina (P5)

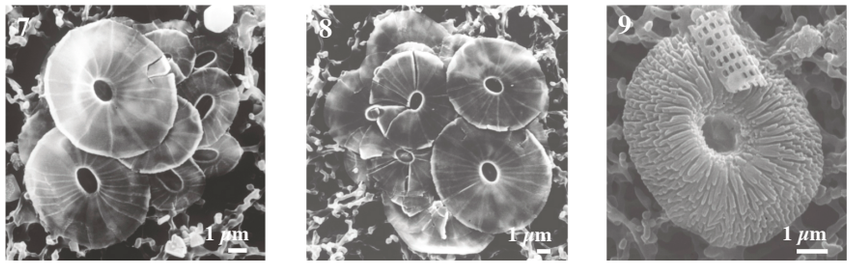
coccosphere
Gabgab Beach (G2)



Umbellosphaera irregularis collapsed coccospheres
Nathan's Dent

Facpi Island (P4)

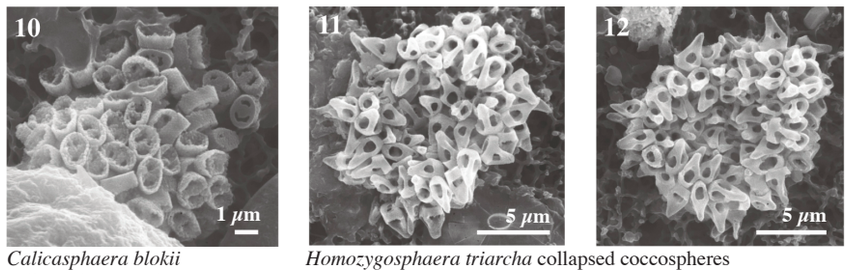
Facpi Island (P4)



Umbellosphaera irregularis type 0 collapsed coccospheres
Nathan's Dent

Nathan's Dent

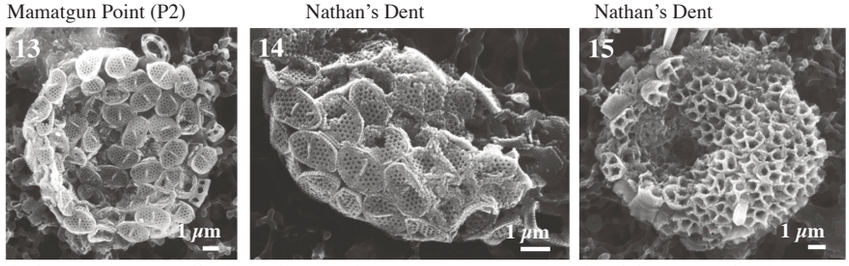
Umb. tenuis type IV coccolith
Gabgab Beach (G2)



Calicasphaera blokii collapsed coccosphere
Mamatgun Point (P2)

Homozygosphaera triarcha collapsed coccospheres
Nathan's Dent

Nathan's Dent



Poricalyptra magnaghii collapsed coccospheres
Nathan's Dent

Calcidiscus quadriperforatus collapsed coccosphere
Nathan's Dent

	south ←															north →
	C1	C2	C3	P1	P2	P3	ND	P4	CG	A2	P5	A1	A4	A3	G2	G1
Diatoms	62928	67525	49972	58510	47464	46211	48420	17971	39345	116661	65137	103466	95287	95705	91764	86033
Coccolithophorids	179	0	60	0	478	657	2687	299	299	60	597	0	60	119	1075	0
Dinoflagellates	836	1672	358	597	657	657	1134	1075	955	597	657	776	716	1313	1493	896
Silicoflagellates	0	0	0	0	0	0	0	60	0	0	0	0	0	0	0	0
Chrysophytes	60	0	0	60	60	0	0	0	0	0	119	0	0	0	0	0
Meringosphaera	0	0	0	0	60	0	179	119	60	0	0	0	0	0	0	0
Foraminifera	119	179	179	119	60	60	60	0	60	119	119	239	179	179	0	179
Radiolaria	0	0	0	0	60	0	0	60	0	0	179	0	60	0	0	0
Tintinnids	0	0	0	299	0	0	0	0	0	0	0	0	0	0	0	60
Total	64122	69376	50569	59584	48838	47584	52479	19583	40718	117437	66808	104481	96302	97317	94332	87167

Table 3: Absolute abundances (in cells/L) of some of the microplankton groups at each sampling site

count. Two of the illustrated specimens from Nathan's Dent belong to type 0, as does another coccosphere from Agat (A4) (not shown here).

Umbellosphaera tenuis (Kamptner) Paasche

Pl. 5, fig. 9

Only one loose coccolith was found in this study, from Gabgab Beach (G2).

Calicasphaera blokii Kleijne

Pl. 5, fig. 10

A single specimen was observed from Mamatgun Point (P2).

Homozygosphaera triarcha Halldal & Markali

Pl. 5, figs 11–12

Two specimens were encountered from Nathan's Dent.

Calcidiscus quadriperforatus (Kamptner) Quinn & Geisen

Pl. 5, fig. 15

A single specimen was found from Nathan's Dent.

Poricalyptra magnaghii (Borsetti & Cati) Kleijne

Pl. 5, figs 13–14

Two specimens were found at Nathan's Dent.

6. Discussion

6.1 Absolute abundances

Coccolithophorids are known to form coastal blooms in restricted bays and fjords (e.g. Berge, 1962; Blackburn & Cresswell, 1993), and can occur in high concentrations in mature upwelled waters (Mitchell-Innes & Winter, 1987). They are usually uncommon in coastal microplankton assemblages, however, being frequently outnumbered by diatoms, and sometimes by dinoflagellates (Table 3; see also Konno & Jordan, 2006). In those studies where counts have been performed, abundances are often very low (10^2 cells/L), but may reach higher concentrations (10^5 cells/L) occasionally (e.g. Konno & Jordan, 2006). Only at two sampling sites in the present study did absolute abundances exceed 1000 cells/L. These abundances are much lower than those usually recorded in open-ocean waters in subtropical/tropical regions, where coccolithophorids reach up to 10^4 cells/L, albeit with lower abundances in surface-waters (e.g. Hagino et al., 2000; Cortés et al., 2001). They are also lower than most of the absolute abundances recorded in the marginal seas along the western Pacific Ocean (Okada & Honjo, 1975).

6.2 Species diversity

The species diversity of subtropical/tropical coastal coccolithophorid assemblages is highly variable, with fewer than five species having been recorded from Indonesian mangrove areas (Inouye, 1988) and a Mediterranean lagoon (Sarno et al., 1993) to more than 20 from around Baja California (Hernández-Becerril et al., 2001), Palau (Konno & Jordan, 2006), Puerto Rico (Tsutsui et al., unpub. obs., 2018) and Guam (Table 5). These numbers are very low compared with open-ocean assemblages, however, where the diversity may reach >100 taxa (e.g. Hagino et al., 2000; Jordan & Winter, 2000, as summarised in Jordan et al., 2000). It should be noted that none of the coastal coccolithophorid species

that have benthic stages were recorded in our samples, although *C. neohelis*, which lives on the sandy seafloor in shallow seas, was present at four locations around Guam, as well as in the inner lagoon in Puerto Rico (Tsutsui et al., unpub. obs., 2018) and in Takapoto and Takaroa in the South Pacific (Jordan & Riaux-Gobin, 2019 [this issue]).

In the marginal seas around Indonesia (Okada & Honjo, 1975) and Palau (Konno & Jordan, 2006), *G. oceanica* has often been one of the most numerous species in the coccolithophorid assemblages; however, it was surprising that, in this study, no cells of *G. oceanica* were encountered. This may be associated with the depth of the seabed, the sampling in Guam having been conducted in deeper waters than in Palau, where most of the samples were collected in shallow lagoons containing the highest abundances of *G. oceanica* recorded in waters of <5m depth (Konno & Jordan, 2006). The shelf is also very narrow on the south-western side of Guam, where most of our samples were taken from. Conversely, *U. irregularis* and *D. tubifera* were the most common species in Guam, but they were only recorded at one shallow site in Palau (Konno & Jordan, 2006).

Comparing the assemblages of Guam and Palau more closely, 13 species were common to both, with 10 found only in Guam, and 10 found only in Palau. In Guam, there were both hetero- and holococcolithophorids, but in Palau only the former; however, samples taken subsequently in Palau, later in the 'wet' season (November 2006 and October 2007), rather than in the peak rainfall period (June–July 2005), revealed the presence of a holococcolithophorid species in each year – *C. blokii* and *Helladosphaera cornifera*, respectively. The 2006 dataset had 14 species common to the Guam assemblage, and included some species not present in the 2005 Palau dataset (Kijima et al., unpub. obs., 2018). In Guam, holococcolithophorids were observed in September, while in Palau they were observed in October–November, but not in June–July. So their presence could be seasonally-controlled. Further sampling in the near future will target the 'dry' season (February–March).

7. Summary

Here, we have reported for the first time on the presence of coastal coccolithophorid assemblages around Guam. These assemblages closely resemble those found in Palau (Konno & Jordan, 2006), although some differences exist. Overall, absolute abundances and species diversity are lower than those of open-ocean waters in subtropical/tropical regions (e.g. Hagino et al., 2000; Cortés et al., 2001).

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