

Syracosphaera azureaplaneta sp. nov. and revision of *Syracosphaera corolla* Lecal, 1966

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Abstract Here we show that the extant coccolithophore *Syracosphaera corolla* Lecal, 1966 comprises two consistently different non-intergrading morphotypes characterised respectively by exothecal coccoliths with wide and narrow central-areas. These are interpreted as separate species and so a new species is described, *S. azureaplaneta*, and a revised description is given for *S. corolla*.

Keywords Coccolithophores, *Syracosphaera*, extant

1. Introduction

As a result of intensive study and careful taxonomic work by many researchers, coccolithophores, are one of the best documented groups of oceanic phytoplankton as well as having an exceptionally good fossil record. This gives them unique potential for a range of types of biodiversity studies and also means it is particularly worthwhile completing their taxonomic documentation. Here we document an addition to one of the most fascinating coccolithophore genera, *Syracosphaera* Lohmann, 1902.

Syracosphaera corolla Lecal, 1966 is a *Syracosphaera* species with unusually prominent exothecal coccoliths with the distal flange greatly expanded and so resemble *Umbellosphaera* Paasche in Markali & Paasche, 1955. Indeed, it was placed in *Umbellosphaera* by Gaarder in Heimdal & Gaarder (1981) and in a separate genus, *Gaarderia*, within the *Umbellosphaeraceae* by Kleijne (1993). However, with better images and a more detailed understanding of the coccolith structure it became clear that the body coccoliths are typical of *Syracosphaera* and that the exothecal coccoliths, whilst distinctive, fall within the type of variation shown by *Syracosphaera*. Hence, the species was placed in *Syracosphaera* in the syntheses of Young et al. (2003) and Jordan et al. (2004). In particular it shows close affinities to *Syracosphaera dilatata* Jordan et al., 1993 and to *Syracosphaera arethusae* (Kamptner, 1941) Triantaphyllou et al., 2016 (synonym *Syracosphaera didyma* Kleijne & Cros, 2009). For an overview of diversity within *Syracosphaera* see Young et al. (2003) and the Nannotax website (Young et

al. 2018) and for their coccolith structure see Young et al. (2004) and Bown et al. (2017)

2. Materials and methods

This contribution is based primarily on review of our collections of scanning electron micrographs of extant coccolithophores. These were collected over an extended period and from diverse environments. Primarily though these are samples collected by vacuum filtration of sea water onto filter membranes (typically 0.2 to 1 µm pore size). The type material is curated in the Natural History Museum, London.

3. Results

Syracosphaera corolla is not common but has been widely reported from all oceans and from the equator to the sub-Arctic (e.g. Kleijne 1993; Okada & Honjo 1973) and our observations confirm this. Reviewing images of the species revealed that there are two distinct morphotypes within it. The primary differences between them are in exothecal coccolith form and most conspicuously in the relative width of the central-area, which may be broad (length ca 2x width) or narrow (length ca 4x width) (see Plate 1 and text-fig. 1). The form with exothecal coccoliths with a broad central-area is the most common, in these the central-area is floored by a flat but rather irregular arrangement of laths. The central-area is also often slightly constricted at the centre and there may be openings at either end. The flange is typically strongly ridged with both sutural ridges and additional ridges. In

the other form the exothecal coccoliths the central-area as well as being narrower, is more also straight-sided and is floored by regularly-arranged radial laths which slope downwards from the edge of the central-area toward the long axis so that the base of the central-area has a valley-like form. The flange is usually smooth, with weak sutural ridges but no other ridges. In other respects, the exothecal coccoliths of the two morphotypes are similar, both having conspicuous anticlockwise obliquity of the elements in distal view, low tubes and narrow proximal flanges.

Systematic review of our images and of published images of *S. corolla* further showed that these two types of exothecal coccoliths could be consistently distinguished and that they did not co-occur on the same coccosphere. The body coccoliths associated with them do not differ in any obvious way and there is no clear pattern to their biogeography (both forms occur in the Indian, Pacific and Atlantic oceans and in both tropical and temperate waters), they can also co-occur in single samples.

Coccolith size and distribution on the coccosphere

The exothecal coccoliths on the narrow central-area form appeared to be larger than those on the broad central-area form, so we measured exothecal and body coccoliths on 30 specimens. This confirmed the observation of larger size for the narrow central-area form (4.5-7.0 μm vs 3.5-6.0 μm ; text-fig. 2.). It also appears that the body coccoliths on the narrow central-area form are slightly larger than on the broad central-area form (typically 2.0-4.0 μm vs 1.5-3.5 μm) (text-fig. 2.). Finally, there is more variability in exothecal coccolith size on the narrow central-

area form - primarily because individual coccospheres often have a few smaller exothecal coccoliths.

In both forms there is a tendency for the exothecal coccoliths to occur in a ring around one end of the coccosphere, with their long-axes parallel to the length of the coccosphere. This is presumably the flagellar pole, as was reported by Lecal (1966). This pattern is most consistently shown in the broad central-area form, whilst in the alternate form the exothecal coccoliths may be extend further over the coccosphere or indeed even cover it completely.

4. Discussion

The consistency of the difference between the two exothecal coccolith forms, and the fact that the morphology is paralleled by differences in coccolith size and arrangement on the coccosphere strongly suggest that these two forms are genotypically discrete. The absence of intermediates suggests that they should be considered as separate species, rather than sub-species. *Syracosphaera corolla* was originally described by Lecal (1966) and it is very unlikely that any type material has survived. However, the illustrations are high-quality transmission electron micrograph images of both a body coccolith and an exothecal coccolith (Lecal, 1966, plate 1 figs 1-2). The exothecal coccolith image distinctly shows a narrow central-area with well-formed radial laths and a wide flange with only sutural ridges. Clearly, this is the narrow central-area form, and so the name *corolla* must apply to this type. A new name is therefore required for the broad central-area species. This conclusion is indisputable, even though it is slightly unfortunate since the broad central-area form appears to be more common and has been illustrated more often. The new species is described below and an emended description is given for *S. corolla*.

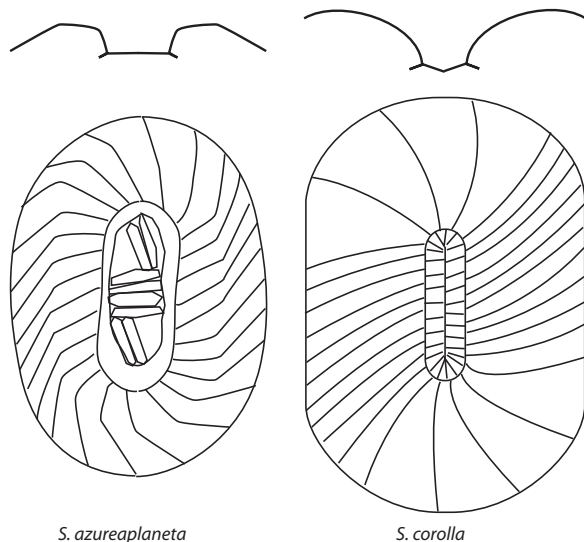


Fig. 1 Drawings of exothecal coccoliths of *S. azureaplaneta* and *S. corolla* in plan view and cross-section, based on tracings of actual specimens.

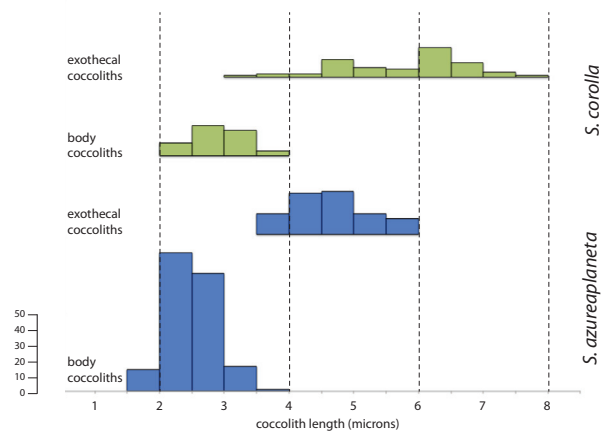


Fig. 2 Coccolith size variation in *S. azureaplaneta* and *S. corolla*. Measurements made on SEM images, with 4-20 coccoliths measured on each of 35 coccospheres. Vertical scale is count frequency.

5. Systematic taxonomy

Syracosphaera azureaplaneta sp. nov.
Pl. 1, figs 1-4

Synonymy:

Syracosphaera corolla (Lecal, 1966); Okada & McIntyre, 1977, pl. 6, figs 1-2; Nishida, 1979, pl. 6, fig. 4; Winter & Siesser, 1994, fig. 107; Young et al., 2003, pl. 19, figs 14-15; Malinverno et al., 2008, fig. 76.
Umbellosphaera corolla (Lecal, 1966) Gaarder in Heimdal & Gaarder, 1981, pl. 6, figs 53, 57.
Gaarderia corolla (Lecal, 1966) Kleijne, 1993, pl. 6, fig. 3-5; Cros & Fortuño, 2002 fig. 29 A.

Derivation of name: From Latin *azureus*, blue (adjective, feminine form *azurea*), and *planeta*, planet (noun, feminine). Named for the BBC documentary series Blue Planet in recognition of its work and that of its presenter, Sir David Attenborough, in promoting understanding of the marine realm.

Description:

Coccosphere: Normally seen collapsed but coccosphere appears to be ovoid with about 25-50 body coccoliths covering the coccosphere and circling of 6-12 exothecal coccoliths at the broader end of the sphere. On undisturbed coccospheres the body coccoliths are mostly arranged with long axes perpendicular to the length of the coccosphere, whilst exothecal coccoliths have their long axes parallel to the length of the coccosphere (e.g., Pl. 1, fig. 2). Possible appendages seen on a few collapsed coccospheres extending from the broader end of the coccosphere (e.g., Pl. 1, fig. 2).

Circum-flagellar coccoliths: These are almost always covered by the exothecal coccoliths but no specimens with spines or other differentiation from the regular body coccoliths have been seen.

Body coccoliths: Irregularly-elliptical, murolith coccoliths, 1.5-3.5µm long, with well-developed distal flange. Central-area floored by single cycle of radial laths without a separate axial structure. Proximal flange narrow, but always present. Mid-wall flange absent, but a well-developed circling of spines occurs in its place, these are typically shorter than the distal flange width but longer than the proximal flange width, so they are visible in proximal view but not in distal view (e.g., Pl. 1, fig. 1). Distal flange well-developed, width varies and it may be weakly asymmetric. Distal flange elements have sutural ridges and show distinct sinistral obliquity in distal view; these elements continue into the tube, where they show weak anti-clockwise imbrication.

Exothecal coccoliths: Similar to the body coccoliths but with much broader distal flange, and so significantly larger (3.5-6.0µm) (text-fig. 2.). Typically oblong with parallel sides and rounded ends and maybe slightly constricted in the middle. Central-area broad (length ca 2x width) floored by radial laths, but these are irregularly disposed, there is no axial structure, single laths may span the central-area (e.g., Pl. 1, fig. 3), and some specimens have lunate openings at either end of the central-area (e.g., Pl. 1, fig. 4). The distal flange usually shows both sutural ridges and additional ridges, which may run either radially (e.g., Pl. 1, fig. 4) or concentrically (e.g., Pl. 1, fig. 2). In profile the flange usually shows distinct flexure (text-fig. 1) rather than being continuously curved. Mid-wall flange spines are only very occasionally seen (e.g., Heimdal & Gaarder, 1981, fig. 57; Nishida, 1979, pl. 6, fig. 4) and only in side views; this may be because they are very short, or because they are often absent.

Variation:

The exothecal coccoliths are quite variable in ornamentation, shape and arrangement of the central-area laths but these characters seem to be intergradational and to vary on coccospheres so they do not seem to define additional species

Life cycle:

Not known - combination coccospheres have not been observed. The closely related species *S. arethusae* (formerly *S. didyma*), however, has been shown by Triantaphyllou et al. (2016) to form combination coccospheres with a holococcolith previously referred to as *Homozygosphaera arethusae*, so it is likely they do have a holococcolith phase, and possibly with other species of *Homozygosphaera* or *Corisphaera*.

Holotype:

Specimen illustrated on Plate 1, fig. 1. Collected from the South Atlantic during the AMT18 research cruise of the R.R.S *James Clark Ross*. Sample AMT18-CTD089 48m, image NHM-JRYSEM-288-65. Collected from 32.18°S; 29.83°W on 2nd Nov 2008.

Distribution.

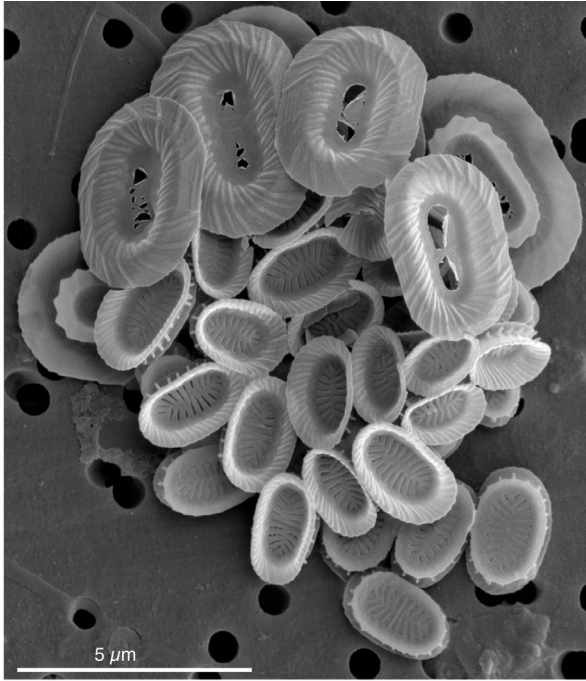
S. azureaplaneta has a very broad distribution occurring from the tropics to the sub-arctic and in all the major oceans.

Syracosphaera corolla Lecal, 1966 emend
Pl. 1, figs 5-7

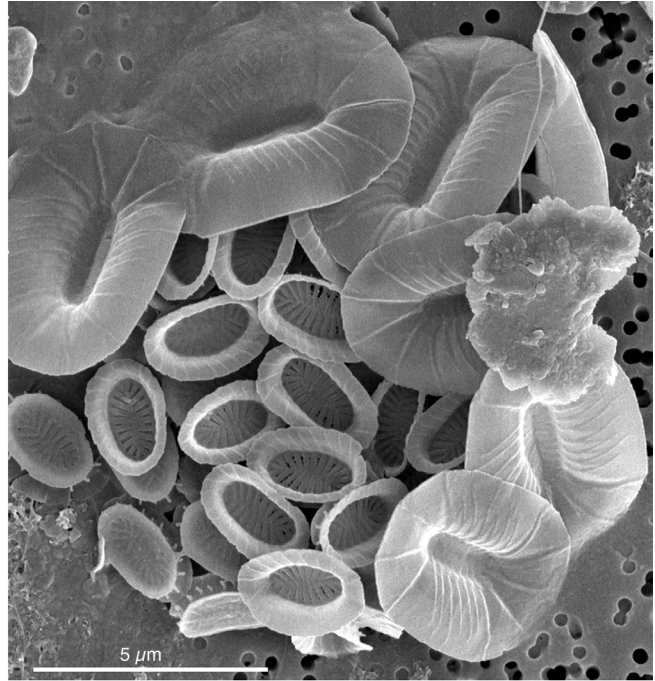
Synonymy:

Syracosphaera corolla Lecal, 1966, pl. 1, figs 1-4; Young et al., 2003 pl. 19, fig. 13;

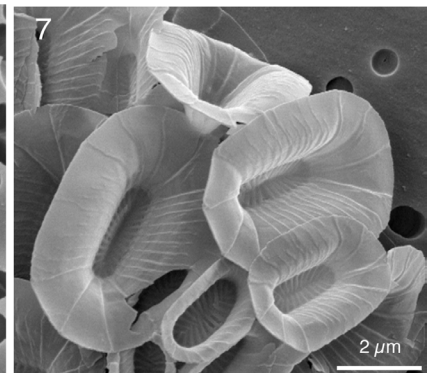
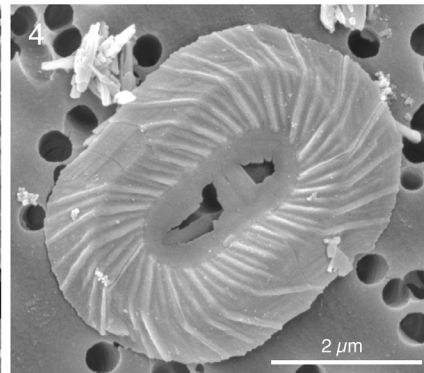
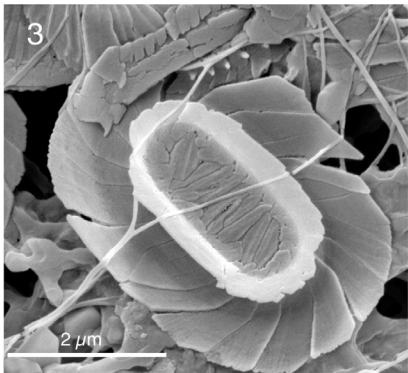
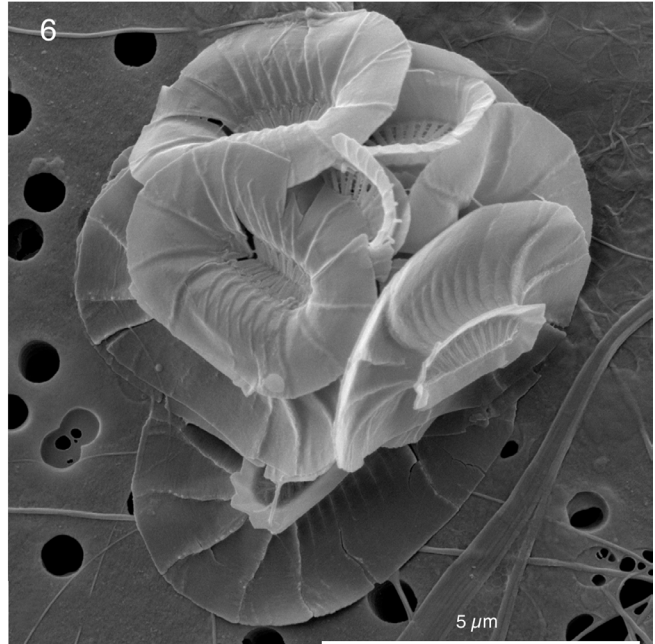
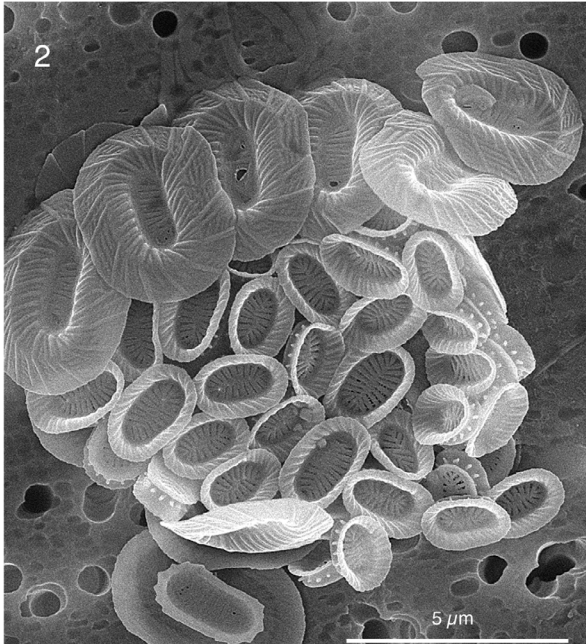
Plate 1



1-4 *S. azureaplaneta*



5-7 *S. corolla*



Umbellosphaera corolla (Lecal, 1966) Gaarder in Heimdal & Gaarder, 1981, pl. 6, fig. 56.

Gaarderia corolla (Lecal, 1966) Kleijne, 1993; Kleijne (1993) pl.6, fig. 6; Cros & Fortuño, 2002 fig. 29 B-D. NB Lecal (1966) used both the names *Syracolithus corolla* and *Syracosphaera corolla*, but this was corrected by Loeblich and Tappan (1968) to *Syracosphaera* (*Syracolithus*) *corolla*.

Emended description:

Following recognition that *S. corolla* as traditionally understood is actually two species, the name *S. corolla* is now restricted to the species with exothecal coccoliths with narrow central-areas.

Coccosphere: Similar to those of *S. azureaplaneta* but exothecal coccoliths may extend over entire surface and show significant variation in size.

Body coccoliths: Very similar to those of *S. azureaplaneta* but slightly larger; 2.-4 μ m vs. 1,5-3.5 μ m (text-fig. 2.).

Exothecal coccoliths: Similar to those of *S. azureaplaneta* but: central-area narrow (breadth ca 4x length); central-area base V-shaped in profile and with regularly arranged laths; distal flange smooth except for weak sutural ridges; sutural ridges also present on the proximal side of the distal flange. The ends of the distal flanges are typically formed by only 3 or 4 elements with wide ends, as opposed to more numerous and narrower elements in this area in *S. azureaplaneta* (text-fig. 1). We have not observed mid-wall spines on exothecal coccoliths of *S. azureaplaneta* and they are clearly not present on some specimens (e.g. Pl. 1, fig. 6). The coccoliths are also slightly larger - *S. corolla* exothecal coccoliths are predominantly 4.5-7.0 μ m long vs 3.5-6.0 μ m for *S. azureaplaneta* (text-fig. 2). They also show a wide total range of sizes (from 3 to 8 μ m), reflecting the fact that there is often strong variation in size on single coccospheres, typically with large coccoliths in a ring at one end of the coccosphere and variable size coccoliths over the rest of the surface.

Acknowledgements

The images used in this study came from samples collected on many different cruises with the assistance of numerous colleagues and diverse funding. We particularly thank our friends Babette Boeckel, Martine Couapel, Jose Fortuño, Markus Geisen and Claudia Sprengel who all took images used in the plate. Elisa Malinverno and Helge Thomsen are thanked for constructive reviews.

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Plate 1 Figs 1-4 *Syracosphaera azureaplaneta*, sp. nov.

1. Holotype, collapsed coccosphere. Image NHM-JRY288-65. Sample AMT18-CTD089 48m, South Atlantic.
2. Collapsed coccosphere, note coiled appendage at top of image. Image GARDCOR(F3K05-40). Sample F3K05; W. Mediterranean (Alboran Sea).
3. Proximal view of isolated coccolith. Image NHM-JRY114-48; Sample P233-1, 5m, NE Atlantic (Canaries).
4. Distal view of isolated coccolith. Image NHM-JRY112-N10U05; Sample N10U05, South Atlantic sediment trap.

Figs 5-7 *Syracosphaera corolla*, emend

5. Collapsed coccosphere, same scale as fig.1, so showing the larger size of the *S. corolla* exothecal coccoliths. Image NHM-JRY193-80; Sample MATER 69-12 50m, W. Mediterranean (Alboran Sea).
6. Small coccosphere almost entirely covered by exothecal coccoliths. Note absence of mid-wall spines. Image NHM-JRY289-38. Sample AMT18-CTD089 72m, South Atlantic.
7. Detail of exothecal coccoliths, note size variation. Image NHM-JRY288-39. AMT18-CTD089 48m, South Atlantic

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