

New species of the coccolithophore *Florisphaera* Okada and Honjo 1973

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ABSTRACT: Eight new living species of the genus *Florisphaera* are described from an exceptionally rich water sample from the Indian Ocean. Five of them have been previously illustrated from diverse localities in the global ocean.

INTRODUCTION

In the course of an analysis of the morphological diversity and intraspecific variability of coccolithophores recovered from the HV Melville Hydroacoustic and Biological Sampling Cruise in the Indian Ocean we encountered a community exceptionally rich in coccospheres of *Florisphaera*. It was collected at a depth of 120m on the eastern side (33°17.91' S, 45° 21.72' E) of the Indian Ocean (Sample VANC10MV07D). The three formally described varieties (*profunda profunda* Okada and Honjo 1973, *profunda elongata* Okada and Honjo 1980, *rhinocera* Quinn et al. 2005) of the hitherto monospecific genus *Florisphaera* were insufficient to describe the morphologic diversity exhibited by coccospheres and coccoliths in the *Florisphaera* community recovered from the sample, and Kahn (2007) informally introduced seven varieties (C to I) among which five have been previously illustrated from other oceanic localities (Aubry 2012). Our forthcoming analysis of intraspecific variability of the coccolithophores in the deep photic zone, and the completion of *Cenozoic Coccolithophores* (Aubry, in press), prompt us to formally describe these informal varieties as new species.

MATERIAL AND METHODS

Material

The species described here are part of the deep photic zone community (DPZ) recovered from a single sample (see above) that was prepared by vacuum filtering of 5 liters of sea water onto a polycarbonate (Osmonics) filter 47mm in diameter with a 0.8µm pore size. Half of the filter was made available to us by Colomban de Vargas (IMCS, Rutgers; now CNRS Roscoff, France). Coccospheres were unusually abundant in this sample, those of *Florisphaera* (42.3%) dominating the community.

Methods

Two triangular 4mm² subsections of the osmonics filter were mounted onto separate stubs and sputter coated with gold and palladium at the Electron Imaging Facility, Division of Life Sciences at Rutgers, the State University of NJ, and analyzed with a FEI Quanta 400 E.S.E.M. in the Geology Department at Bucknell University. The scanning of the entire triangular preparation was conducted at a magnification of 2000x. A total of 177 coccospheres of *Florisphaera* were encountered. Each was

carefully examined using magnification up to 120,000x, and photographed. Several morphologic characters were subsequently measured (Kahn 2007). The species taxonomy below is based on these measurements in addition to general morphology.

TAXONOMIC BACKGROUND

Unclassified since its discovery, *Florisphaera* has recently been shown to be a coccolithophore (Young et al. 2010). Its coccosphere is highly unusual in shape and organization. Likewise its polygonal coccoliths (= polygoliths, Quinn et al. 2005) are highly unusual. Different terminologies have been used to orient both coccospheres and polygoliths. We follow here the terminology of Aubry (2012) applicable to other similarly shaped coccospheres (as those of *Gladiolithus* and *Solisphaera*). The conical/hemispherical coccosphere of *Florisphaera* is oriented with respect to its axis of rotation, the base being referred to as “anterior” and the apex as “posterior”. Accordingly, with the anterior-posterior axis oriented north-south, the polygoliths may be described in terms of anterior and posterior sides, right and left sides, in addition to proximal and distal faces.

TAXONOMIC DESCRIPTIONS

The seven species formally named below are described from a single sample. Their type locality is Indian Ocean Site VANC10MV07D (33°17.91'S, 45°21.72'E). The sample of sea water was taken on 3 May 2003 (between 16:49 and 17:45 h) at a depth of 120m where seawater temperature was 18 °C and salinity 35.67‰.

Florisphaera acanthos Kahn and Aubry, n. sp.

Plate 1, figure a

Florisphaera profunda profunda in YANG and Wei 2003, pl. 1, fig. 3
“*Florisphaera profunda* + spine” in YOUNG et al. 2003, pl. 39, fig. 9
?*Florisphaera profunda profunda* in QUINN et al. 2005, fig. 2
Florisphaera profunda in AUBRY and KAHN 2006, pl. 5, figs. d, e
Florisphaera profunda var. G KAHN 2007, pl. 3, fig. A

Latin Description: Coccosphaera hemisphaerica forma, conferta, multis (plus 150) polygolithis dense constricta. Quae

elongantur, aliquantumque dilatantur ad frontem partem. Frons brevem spinae similem extensionem circa tertia parte ab angulo polygolithae dextero sitam ostendere solet. Margo aegre obliqua est ad dexteram spinae, visione distale; latus alterum rectum aut aegre concavum est.

English Description: Coccosphere hemispherical, compact, tightly and densely packed with numerous (>150) polygoliths. The latter elongate, slightly widening towards the anterior side. Characteristically the anterior side exhibits a short, thorn-like projection located at about 1/3 of the distance from the right corner of the polygolith. The edge is slightly oblique right of the spine as seen in distal view; it is straight or gently concave on the other side.

Size: Coccosphere: L = 9.6µm; Coccoliths: Length: 1.5–2.3µm (2.0µm); width: 1.0–2.0µm (1.5µm)

Type material: Rutgers University Micropaleontology Laboratory S.E.M. stub VANC10MV07D_b. Filter-sample collected at type locality.

Type repository: Permanent Collection Center of the Department of Earth and Planetary Sciences, Rutgers University.

Type locality: see above

Holotype: Plate 1, figure a.

Etymology: Gr. *akantha*, thorn; in reference to the thorn-like projection on the anterior side of the polygoliths

Number of coccospheres: 8

Distribution: *F. acanthos* was illustrated from the East China Sea (Yang and Wei 2003). A spine also ornates the anterior side of the polygoliths of the coccosphere seen in posterior face in Quinn et al. (2005, Fig. 2). The spine originates on the distal side of the coccoliths, clearly below the anterior edge rather than just at the edge. It also tends to be hook-shaped. Additionally, the coccoliths are more quadrangular than in *F. acanthos*, and they have irregularly spaced tiny knobs. This morphotype is provisionally referred to *F. acanthos*; it may represent a different species.

***Florisphaera diantha* Kahn and Aubry, n. sp.**

Plate 1, figures b, c

Florisphaera profunda in OKADA 1983, pl. 1, fig. 9
Florisphaera profunda var. *D*KAHN 2007, p. 138, 139, pl. 2, figs. a, b

Latin Description: Coccosphaera hemisphaerica forma, ut veri simile est, 145 polygolithis induta, peraeque ducta. Polygolithae deformes sunt quarum frons et tergum formam inaequaliter serratam habent. Latera dextera sinistraque recta sunt, aliquantum divergentia. Magnitudo coccolitharum valde variat in singulis coccosphaeris, discrimen latitudinis usque ad 1.5µm. Magnitudo etiam inter coccosphaeras valde variat. Polygolithae minores, quae saepe sunt latiores quam longiores, formas habere solent inaequaliores; maiores autem formas habent polygonales, tergis et frontibus erugatoribus. Haec species est inter omnes alias unica, nam brevissimis artissimisque polygolithis induta est, atque polygolithae magnam variabilitatem morphologiae ostendunt non solum singulis coccosphaeris sed etiam inter coccosphaeras.

English Description: Coccosphere probably hemispherical with 160 polygoliths on average. Irregularly shaped polygoliths with unevenly serrate posterior and anterior sides. Right and left sides straight, slightly divergent. The size of the coccoliths varies broadly on any single coccosphere, the difference in length as much as 1.5µm. The size also varies considerably among coccospheres. The smaller polygoliths, which are often wider than long, tend to be more irregular in outline; the larger polygoliths are more polygonal with smoother anterior and posterior sides. This species differs from all others in possessing the shortest and narrowest polygoliths, and in the polygoliths exhibiting a broad morphologic variability both on any single coccosphere and between coccospheres.

Size: Coccosphere: Ø = 7.4–10.2µm (8.5µm) x 7.1–9.5µm (8.4µm); Coccoliths: Length: 0.7–2.6µm (1.7µm); width: 0.9–2.4µm (1.4µm)

Type material: Rutgers University Micropaleontology Laboratory S.E.M. stub VANC10MV07D_b. Filter-sample collected at type locality.

Type repository: Permanent Collection Center of the Department of Earth and Planetary Sciences, Rutgers University.

Type locality: see above

Holotype: Plate 1, figure c

Etymology: NL. *Dianthus*, carnation; the shape of the coccoliths is reminiscent of carnation petals.

Number of coccospheres: 32

Distribution: This species was illustrated from the Central Red Sea (Okada 1983).

***Florisphaera erugata* Kahn and Aubry, n. sp.**

Plate 1, figures d, e

Florisphaera profunda var. *H*KAHN 2007, pl. 3, figs. c, d)

Latin Description: Coccosphaera hemisphaerica forma, ut veri simile est (coccosphaerae partim collapsae tantum inventae sunt). Numerus medius coccolitharum per coccosphaeram ~92 est. Polygolithae forma prope quadrangulae. Margo frontis recta est cum angulis rotundis. Et longitudo et latitudo polygolitharum valde variant in singulis coccosphaeris. Haec species est inter alias species unica, nam parvum numerum coccolitharum habet quae sunt forma prope quadrangulae, cum marginibus erugatis.

English Description: The coccosphere is probably hemispherical (only partly collapsed coccospheres were encountered). The average number of coccoliths/coccosphere is ~92. Polygoliths almost rectangular. The anterior edge is straight with rounded corners. Both the length and the width of the polygoliths vary significantly on any single coccosphere. This species differs from other species by its low number of coccoliths which are almost rectangular, with smooth edges.

Size: Coccosphere: L = 6.1µm; Coccoliths: Length: 1.7–3.1µm (2.3µm); width: 1.1–3.2µm (1.7µm).

Type material: Rutgers University Micropaleontology Laboratory S.E.M. stub VANC10MV07D_b. Filter-sample collected at type locality.

Type repository: Permanent Collection Center of the Department of Earth and Planetary Sciences, Rutgers University.

Type locality: see above

Holotype: Plate 1, figure d.

Etymology: *L. erugata* = smooth.

Number of coccospheres: 6

Distribution: This species is only illustrated from the Indian Ocean.

***Florisphaera heliantha* Kahn and Aubry, n. sp.**

Plate 1, figure f; Plate 2, figure a

Florisphaera profunda in Gupta et al. 2005, pl. 2, fig. 1
Florisphaera profunda var. *E* Kahn 2007, pl. 2, figs. c, d

Latin Description: Coccospaera ex ~160 coccolithis constans, cum margine frontis quae est incongruenter incisa. Frontis delineatio polygolitharum valde variat, etiam in singulis coccosphaeris, sed res insignis est locus incisionis prope angulum dexterum frontis. Latus sinistrum polygolitharum convexum est, dexterum aliquantum cavum. Discrimen est inter Polygolithas huius speciei et eas *F. profundae status novi*, nam incisio incongruenter potius quam congruenter sita est, et curvatura laterum sinistrorum et dextrorum contraria est. *F. profundae* latus sinistrum cavum, dexterum convexum est. Polygolithae *F. helianthae* minus elongatae sunt quam aliarum specierum.

English description: Coccosphere consisting of ~160 coccoliths with an asymmetrically indented anterior edge. The outline of the anterior side of the polygoliths varies broadly, even on a single coccosphere, but the distinctive character is the location of the indentation close to the right anterior corner. The left side of the polygoliths is convex, the right side slightly concave. The polygoliths of this species differ from those of *F. profunda status novum* in having the anterior indentation asymmetrically rather than symmetrically located, and in the opposite curvature of their right and left sides. In *F. profunda* the left side is concave and the right side convex. Polygoliths in *F. heliantha* are less elongate than in other species.

Size: Coccosphere: $\emptyset = 6.8\text{--}9.6\mu\text{m}$ ($8.1\mu\text{m}$) x $6.6\text{--}9.6\mu\text{m}$ ($8.2\mu\text{m}$); Coccoliths: Length: $1.3\text{--}2.6\mu\text{m}$ ($2.1\mu\text{m}$); width: $1.0\text{--}2.5\mu\text{m}$ ($1.5\mu\text{m}$)

Type material: Rutgers University Micropaleontology Laboratory S.E.M. stub VANC10MV07D_b. Filter-sample collected at type locality.

Type repository: Permanent Collection Center of the Department of Earth and Planetary Sciences, Rutgers University.

Type locality: see above

Holotype: Plate 2, figure a.

Etymology: Gr. *Helios*, sun; in reference to *Helianthus annuus* (sunflower)

Number of coccospheres: 26

Distribution: This species was previously illustrated from the eastern equatorial Indian Ocean (Gupta et al. 2005).

***Florisphaera kinara* Kahn and Aubry, n. sp.**

Plate 2, figure b

Florisphaera profunda profunda, in Okada 1983, pl. 1, Fig. 4
Florisphaera profunda var. *G* Kahn 2007, pl. 3, fig. b

Latin Description: Coccospaera conica forma, cui numerum medium 141 polygolitharum est. Forma marginis frontis polygolitharum admodum propria est. Ab latere sinistro ad dexterum: margo primum aegre convexa est; ad ~1/3 longitudinis, acuta angustaque spina oritur, deinde lata brevisque incisura contenta ad partem sinistram alia spina acuta, cuius margo est aegre curvata. Duae spinae magnitudine aequae sunt, breviores quam spina *F. rhinocerae*. Longitudo polygolitharum inter coccosphaeras variat, sed in singulis coccosphaeris paululum variat. Converso, latitudo polygolitharum magis variat in singulis coccosphaeris quam inter coccosphaeras. *F. kinara* inter alias species unica est, nam latissimas polygolithas habet, et polygolithae eius longissimae sunt (post *F. heliantha*) specierum observatarum.

English Description: Coccosphere conical, with an average of 141 polygoliths. The shape of the anterior edge of the polygoliths is very characteristic. From the left to the right side: the edge is first gently convex; at ~1/3 the length, a sharp and narrow spine occurs, then a broad and shallow notch bounded to its left by another sharp spine at the left of which the edge is gently curved. The two spines are essentially of equal size, and shorter than the spine in *F. rhinocera*. The length of the polygoliths varies between coccospheres but there is little variation on any given coccosphere. In contrast, the width of the polygoliths varies more on any given coccosphere than between coccospheres. *F. kinara* differs from other species in having the widest polygoliths, and its polygoliths are longest (behind *F. heliantha*) of the observed species.

Size: Coccosphere: $\emptyset = 7.6\text{--}12.4\mu\text{m}$ ($9.5\mu\text{m}$) x $8.3\text{--}12.0\mu\text{m}$ ($9.9\mu\text{m}$); Coccoliths: Length: $2.0\text{--}3.2\mu\text{m}$ ($2.6\mu\text{m}$); width: $1.2\text{--}2.6\mu\text{m}$ ($2.2\mu\text{m}$).

Type material: Rutgers University Micropaleontology Laboratory S.E.M. stub VANC10MV07D_b. Filter-sample collected at type locality.

Type repository: Collection Center of the Department of Earth and Planetary Sciences, Rutgers University.

Type locality: see above

Holotype: Plate 2, figure b.

Etymology: Gr. *kinara*, artichoke; in reference to the shape of the coccosphere that is reminiscent of an artichoke.

Number of coccospheres: 20

Distribution: This species was previously illustrated from the Central Equatorial Pacific (Okada 1983).

***Florisphaera paionia* Kahn and Aubry, n. sp.**

Plate 2, figures c, d

Florisphaera profunda var. *profunda* in Okada 1983, pl. 1, fig. 1
Florisphaera profunda in Sprengel 2000, pl. 1, fig. 11
? *Florisphaera profunda* in Hoepfner and Hass 1990, fig. 20
Florisphaera profunda in Frada et al. 2010, pl. 43, fig. 5
Florisphaera profunda var. *C*, Kahn 2007, p. 138, pl. 1, figs. e, f

Latin Description: *Coccosphaera* hemisphaerica forma conferta, dense constricta, quae medium numerum 145 polygolitharum habet. Polygolithae longiores sunt quam latiores, lateribus dexteris et sinistris paene rectis, fronte aliquantum serrata. Polygolitharum morphologia paululum variat singulis coccosphaeris. Haec species inter alias species insolita est ob coccosphaerae confertae formam.

English Description: Cocosphere hemispherical, compact, tightly and densely packed, with an average of 145 polygoliths. Polygoliths longer than wide, with almost straight right and left sides and slightly serrate anterior side. The morphology of the polygoliths varies little on any given coccosphere. This species differs markedly from other species by the shape and packing of the coccosphere.

Size: Cocosphere: $\emptyset = 5.8\text{--}10.3\mu\text{m}$ ($8\mu\text{m}$) x $5.4\text{--}9.6\mu\text{m}$ ($7.7\mu\text{m}$); Coccoliths: Length: $1.4\text{--}2.3\mu\text{m}$ ($2.0\mu\text{m}$); width: $0.9\text{--}2.6\mu\text{m}$ ($1.5\mu\text{m}$)

Type material: Rutgers University Micropaleontology Laboratory S.E.M. stub VANC10MV07D_b. Filter-sample collected at type locality.

Type repository: Collection Center of the Department of Earth and Planetary Sciences, Rutgers University.

Type locality: see above

Holotype: Plate 2, figure c.

Etymology: Gr. *paionia*, peony; in reference to the flower-shaped coccosphere.

Number of coccospheres encountered: 48

Distribution: This species was illustrated from the Equatorial Central Pacific (Okada 1983), the eastern tropical North Atlantic Ocean (Sprenkel et al. 2000), the South Atlantic (Frada et al. 2010) and possibly the north Pacific central gyre (Hoepffner and Haas (1990).

***Florisphaera rosa* Kahn and Aubry, n. sp.**
Plate 2, figures e, f

Florisphaera profunda var. *F* Kahn 2007, p. 139, 140, pl. 2, figs. e, f

Latin Description: *Coccosphaera* hemisphaerica forma ex 145 coccolitharum constans, peraeque ducta. Frons polygolitharum formam habet late triquetram, extentionem acutam efficiens,

atque serrata est margo. Potest esse ut margo tergi quoque serrata sit. Haec species inter omnes alias unica est, nam polygolithis angustissimis induta est. Porro dissimilis est *F. elongatae*, nam frons polygolitharum serrata est potius quam erugata.

English Description: Cocosphere hemispherical consisting, on average, of 145 coccoliths. The anterior end of the polygoliths is broadly triangular, forming an acute protrusion, and the edge is serrate. The posterior edge may also be serrate. This species differs from all others in possessing the narrowest polygoliths. It further differs from *F. elongata* in the anterior end of the polygoliths being serrate rather than smooth.

Size: Cocosphere: $\emptyset = 6.6\text{--}9.2\mu\text{m}$ ($7.6\mu\text{m}$); Coccoliths: Length: $1.4\text{--}4.2\mu\text{m}$ ($2.2\mu\text{m}$); width: $1.1\text{--}2.8\mu\text{m}$ ($1.5\mu\text{m}$).

Type material: Rutgers University Micropaleontology Laboratory S.E.M. stub VANC10MV07D_b. Filter-sample collected at type locality.

Type repository: Collection Center of the Department of Earth and Planetary Sciences, Rutgers University.

Type locality: see above

Holotype: Plate 2, figure e.

Etymology: L. *Rosa*; in reference to the general shape of the coccosphere.

Number of coccospheres: 21

Distribution: Illustrated only from the Indian Ocean

***Florisphaera profunda* Okada and Honjo 1973 status novum** Kahn and Aubry

Florisphaera profunda profunda Okada and Honjo 1973, p. 373, 374, pl. 2, figs. 4, 5

***Florisphaera elongata* Okada and Honjo 1980 status novum** Kahn and Aubry

Florisphaera profunda elongata Okada and Honjo 1973, p. 374, pl. 1, fig. 6; pl. 2, fig. 6, inv.

Florisphaera profunda elongata Okada and McIntyre 1979, p. 2
Florisphaera profunda elongata Okada and McIntyre 1980, p. 81

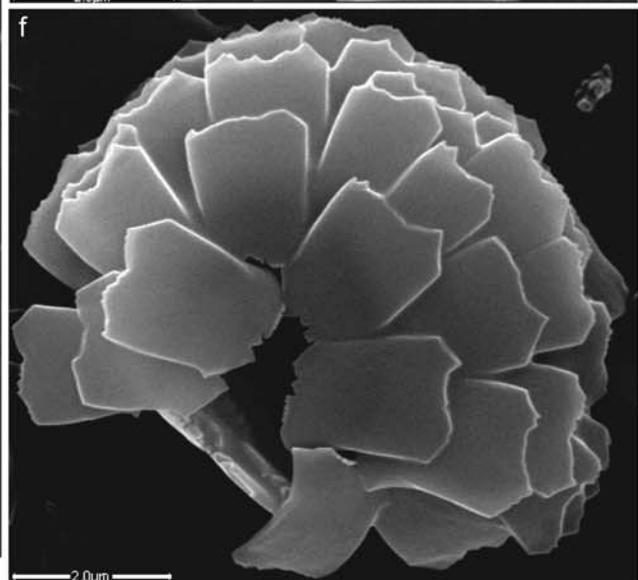
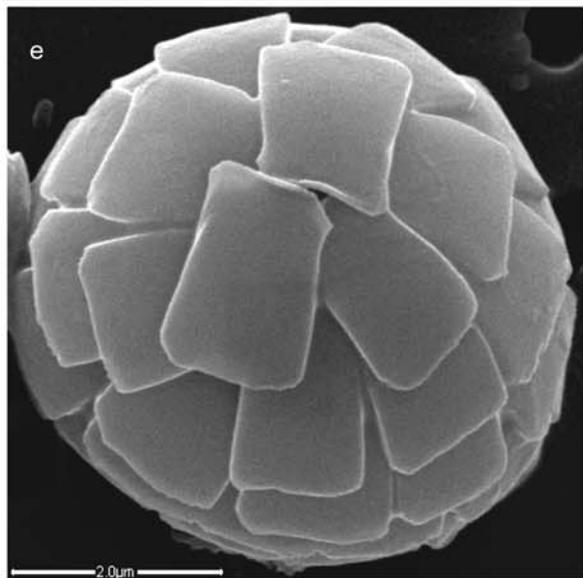
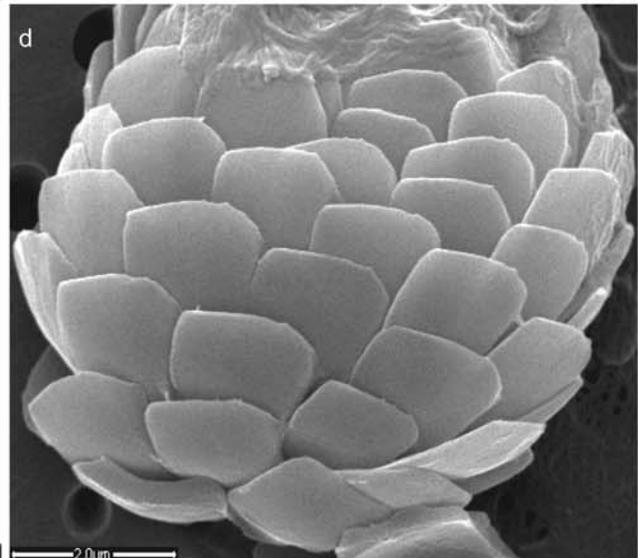
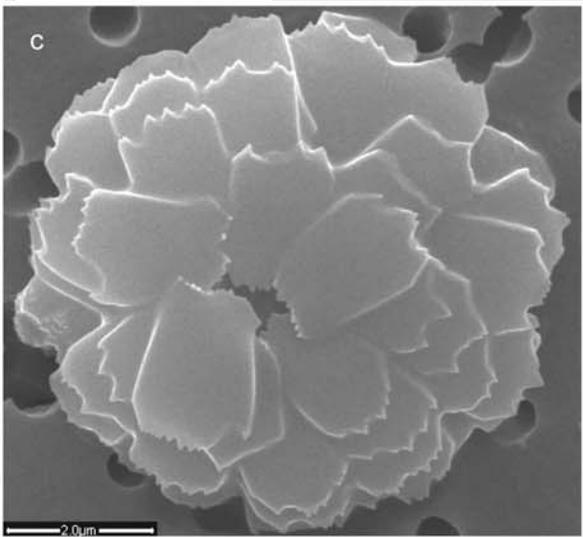
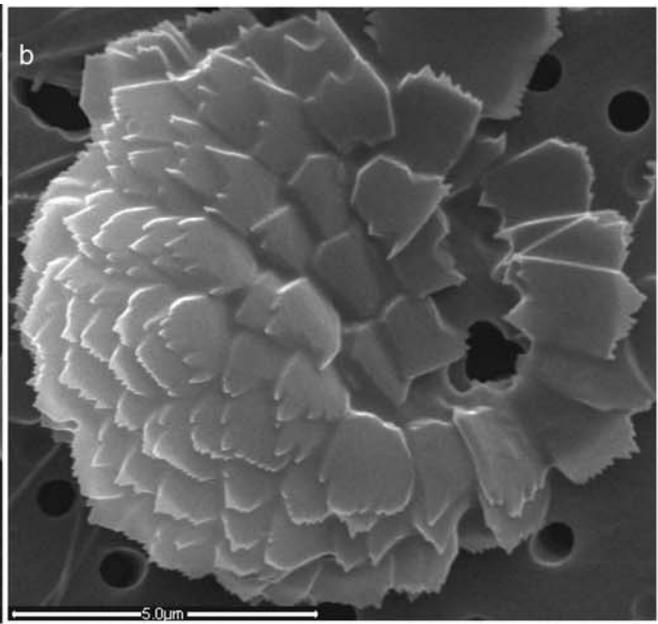
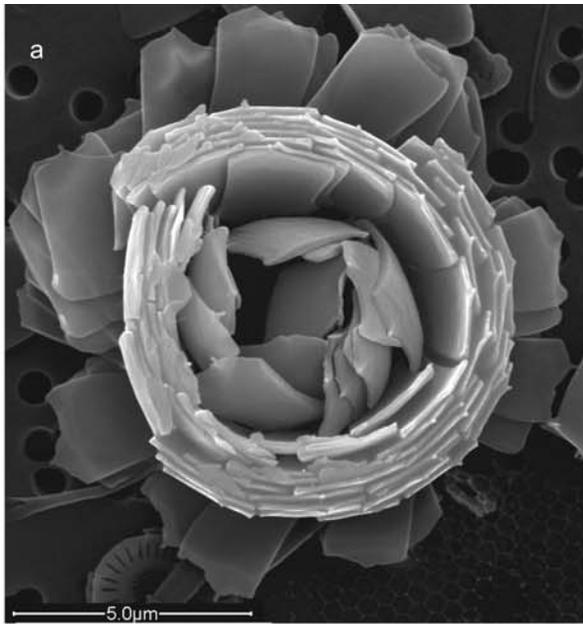
***Florisphaera rhinocera* Quinn et al. 2005 status novum** Kahn and Aubry

Florisphaera rhinocera Quinn et al. 2005, p. 126, figs. 5-8
Florisphaera profunda unknown var. Okada 1983, pl. 1, fig. 8
Florisphaera rhinocera, Kahn 2007, pl. 3, fig. C

PLATE 1

All photographs from the same locality on the eastern side ($33^{\circ}17.91'$ S, $45^{\circ}21.72'$ E) of the Indian Ocean at a depth of 120m (Sample VANC10MV07D).

- a *Florisphaera acanthos* n. sp. Anterior face. Holotype
b,c *Florisphaera diantha* n. sp. posterior face (c) and posterior face and side view (b). b: holotype
d,e *Florisphaera erugata* n. sp. d: side view. e: posterior face. d: Holotype
f *Florisphaera heliantha* n. sp. posterior face.



ACKNOWLEDGMENTS

We are grateful to Colomban de Vargas for providing us with samples from the HV Melville Hydroacoustic and Biological Sampling Cruise (Donna Blackman [Chief scientist] and Erica Goetze [Lead PI biology] Scripps Institution of Oceanography); to Chris Daniel for use of the SEM facilities at Bucknell University. Warm thanks to Erik Collins for the Latin translations of the species descriptions.

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Received March 23, 2012

Accepted March 26, 2012

Published July 15, 2012

PLATE 2

All photographs from the same locality on the eastern side (33°17.91' S, 45° 21.72' E) of the Indian Ocean at a depth of 120m (Sample VANC10MV07D).

a *Florisphaera heliantha* n. sp. posterior face. Holotype

b *Florisphaera kinara* n. sp. side view. Holotype

c,d *Florisphaera paionia* n. sp. c: anterior face; d: posterior face. c: holotype.

e,f *Florisphaera rosa* n. sp. e: side view; f: posterior face. e: holotype

