



Gato hyalinus gen. et sp. nov., an unusual araphid tube-dwelling diatom from Western Pacific and Caribbean islands

CHRISTOPHER S. LOBBAN¹ & J. NELSON NAVARRO²

¹Division of Natural Sciences, University of Guam, Mangilao, GU 96923, USA;
Email: clobban@uguam.uog.edu (corresponding author)

²Pontifical Catholic University of Puerto Rico, Ponce, PR 00717, USA;
Email: nnavarro@live.com

Abstract

A new species of tube-dwelling diatom, unusual in being araphid, is described from benthic coral reef habitats in Guam, Palau, Puerto Rico and Jamaica. *Gato* gen. nov. is heteropolar and heterovalvar, exhibits very fine striae delimiting a narrow and irregular sternum, and possesses a series of rimmed pores on each side of the foot pole. One valve of the frustule has a rimoportula at the foot pole, but both valves possess a rimoportula at the head pole. The generitype, *G. hyalinus* sp. nov. forms small, branched colonies. Individual cells are oval, slightly tapered along the apical axis, 30–40 µm x 13–15 µm, with 60–70 striae in 10 µm. On the foot pole with a rimoportula the rimmed pores are connected to the sternum by diagonal striae; several additional rimmed pores interrupt transapical striae further up both valves. We compare valve structure of *G. hyalinus* with *Florella portoricensis* and *F. pascuensis*, which we report for the first time from the Marshall Islands, and to *Licmophora* spp. We find no taxa to which this genus is related, and can identify no structure potentially homologous to the series of rimmed pores among the diatoms.

Key words: araphid diatom, Bacillariophyceae, coral reefs, tube-dwelling diatom, rimmed pores, rimoportulae

Introduction

Tube-dwelling diatoms (i.e., those that live in mucilage tubes usually of their own making) occur in many marine benthic habitats, from underneath polar ice (Medlin 1990) to tropical reefs (Lobban & Mann 1987, Navarro 1987). In many temperate regions they form macroscopic colonies that resemble brown seaweeds and can reach bloom populations (Cox 1975, 1981, Lobban 1983, 1989), but most tropical colonies are microscopic. Only *Nitzschia martiana* (C. Agardh 1827: 629) Van Heurck (1896: 406) is exceptionally seen with the naked eye (Lobban & Mann 1987, Lobban & Tsuda 2003), but is more commonly discovered with a microscope. The taxonomic diversity in marine tube-dwelling diatoms includes several species of *Berkeleya* Greville (1827: pl. 294) and *Parlibellus* Cox (1988: 19) (Naviculales: Berkeleyaceae) (Cox 1975, 1988, Mizuno 1979, Navarro 1987), several species of *Navicula* Sect. Lineatae (Naviculales: Naviculaceae), several species of *Nitzschia* Hassall (1845: 435) (Bacillariales: Bacillariaceae) (Lobban 1984, 1985), and at least two species of *Gyrosigma* Hassall (1845: 435) (Naviculales: Pleurosigmataceae) (Smith 1856, Sterrenburg 1989, Jansson *et al.* 1994). In addition, *Mastogloia cocconeiformis* Grunow (1860: 578) (Mastogloiales: Mastogloiaceae) forms branched tubes with a single cell at the base of each branch (John 1993, Hein *et al.* 1993). Besides these tube formers, several *Navicula* and *Nitzschia* species cohabit tubes made by other species (Lobban 1984, Basson & Sims 1998). All taxa mentioned above are biraphid, and many are motile within the tubes. However, we encountered an araphid species that forms very small, branched colonies and has an apparently hyaline valve face in LM. We describe this species in a new genus and compare it to some other araphid taxa from Guam, especially *Licmophora* C. Agardh (1827: 628) and two species of *Florella* J.N. Navarro (1982: 248).

Methods

Diatom samples were collected by hand during scuba diving or snorkeling in Guam, Palau and the Marshall Islands (CSL), Puerto Rico and Jamaica (JNN). Live and acid-cleaned samples were observed in LM and SEM as described in our previous work on Puerto Rico and Guam (Navarro 1996; Lobban *et al.* 2010). Referenced specimens except the types are in the authors' collections.

Terminology: In this genus there are both labiate openings, i.e. rimoportulae, and non-labiate openings. To distinguish the latter, and to avoid the assumption that they are homologous to rimoportulae, we adopt the descriptive term "rimmed pore" (*porus marginatus*), which Round *et al.* (1990) used with reference to a small opening in the middle of some valves of *Podocystis* J.W. Bailey (1854: 11).

New species and genus descriptions

Division Bacillariophyta

Class Fragilariophycidae F.E. Round 1990

Order *incertae sedis*

Family *incertae sedis*

Gato Lobban & J.N. Navarro *gen. nov.*

Frustula heteropolara heterovalvaraque, subtiliter striata, sterno angusto irregulari. Striae porosae, uniseriatae, marginem valvarum attingentes. Rimoportula grandior ad polum basalem valvae unae, rimoportula parvior ad polos apicales ambo valvarum. Series pororum marginatorum secus marginem valvarum utrinque poli basalis.

Frustules heteropolar and heterovalvar, finely striated with narrow, irregular sternum. Striae porate, uniseriate, continuing to valve border. Larger rimoportula at foot pole of one valve, one smaller rimoportula at head pole of each valve. Row of rimmed pores along valve margin on each side of the foot pole.

Type species:—*Gato hyalinus* Lobban & J.N. Navarro

Etymology:—From Gr. γάτα, γάτος, cat, with reference to the oblique striae at the foot pole, reminiscent of a cat's whiskers.

Gato hyalinus Lobban & J.N. Navarro *sp. nov.* (Figs 1–21)

Cellulae coloniales in tubis brevibus mucilaginis interdum ramosis. Chloroplasti numerosi lenticulares elongati. Valvae ovaes parum angustatae versus basem, longitudine 30–40 μm, latitudine 13–15 μm. Striae transapicales tenuissimas, ca. 60–70 in 10 μm, paralleles praeter e extremo apicali sterna radians et prope polum basalem obliquaras. Rimoportula poli basalis in palla valvarum; rimoportula poli apicalis ad vel ultra extremum apicali sterna, prope pallam. Pori marginati non solum 3–5 in quoque lato poli basalis, in exemplum valvae rimoportula basali ferens una cum paribus striarum obliquarum e unusquaque versus sternum extensarum, sed etiam aliquot irregulariter in striis transapicalis prope marginem posititis.

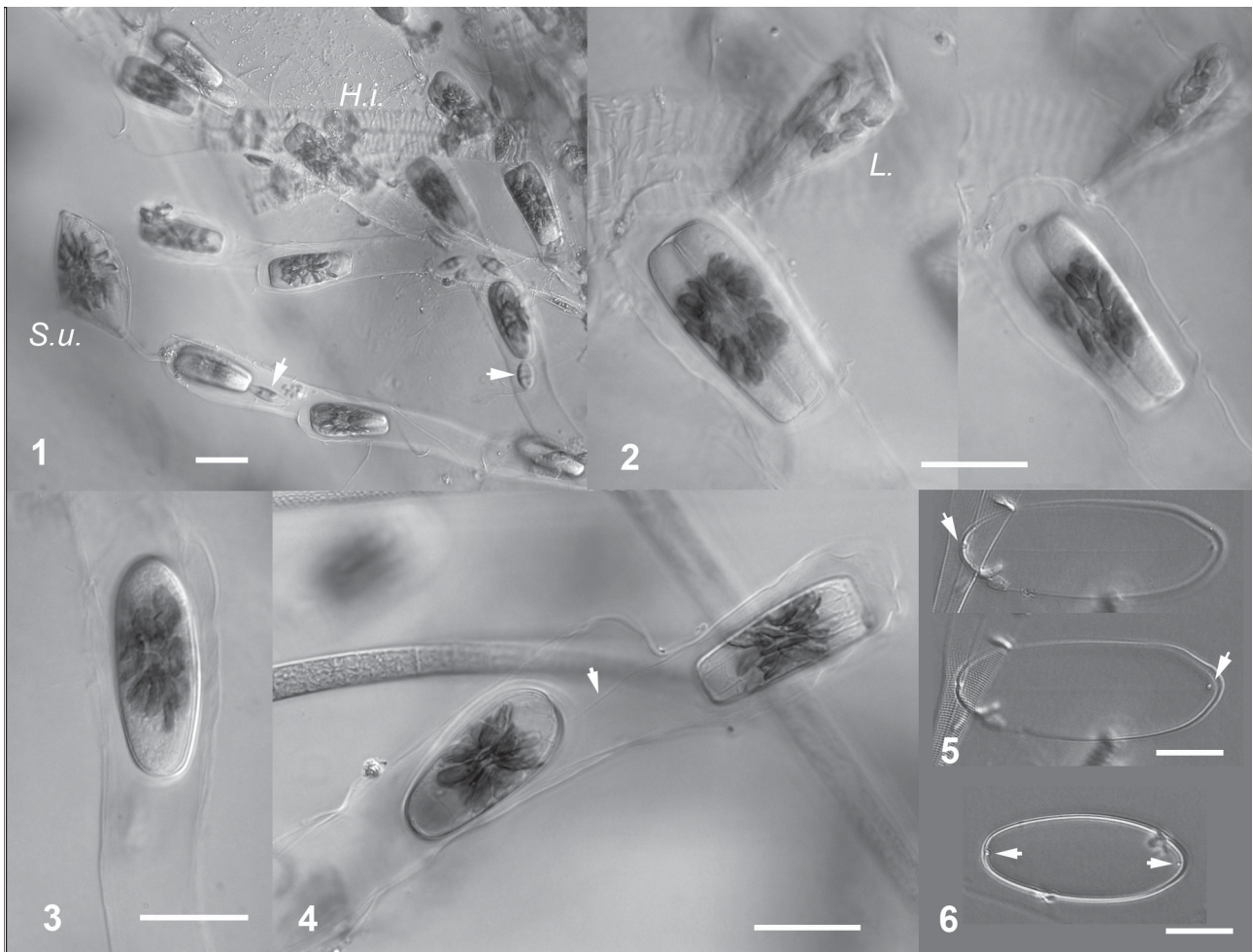
Cells colonial in short, sometimes branched mucilage tubes. Plastids numerous, elongate lenticular. Valves oval, slightly tapered toward foot pole, length 30–40 μm, width 13–15 μm. Transapical striae extremely fine, ca. 60–70 in 10 μm, parallel except radiating from head pole of sternum, and oblique at foot pole. Foot pole rimoportula on valve margin; head pole rimoportulae at or beyond end of sternum, near edge of mantle. Rimmed pores 3–5 on each side of the foot pole, on valve with basal rimoportula associated with pairs of oblique striae extending from each toward the sternum, and several others irregularly placed on transapical striae near margin.

Type:—GUAM. Apra Harbor, GabGab reef, 13° 26' 33.63" N, 144° 38' 34.25" E, acid cleaned material of diatoms, epiphytic on algal turf in farmer fish territories, collected 20 June 2009, GU44Z-15, strewn on microscope slide and filtered onto Millipore® filter paper. (Specimen circled on microscope slide marked CAS #223005, accession #627383, **holotype, designated here**; SEM stub of collection GU44Z-15 [deposited as holotype of the bleakeleyoid diatom *Perideraion decipiens* Lobban in Lobban *et al.* (2011)], CAS #627385, **isotype, designated here**).

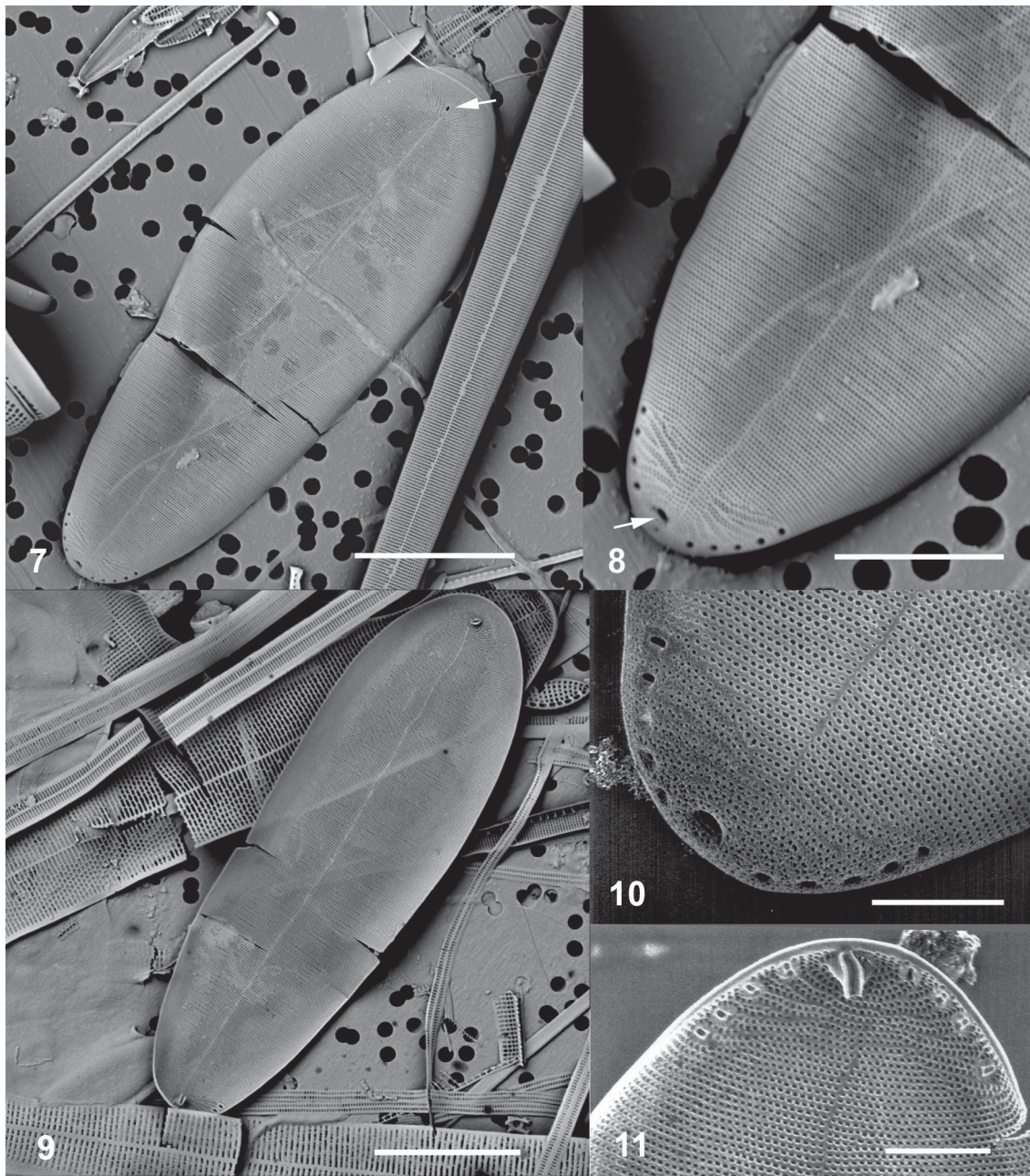
Etymology:—hyaline, with reference to the lack of structure visible in LM.

Additional specimens examined:—GUAM: Agana Boat Basin, epiphytic on algal turf just below low water line, 29 November 1988, *GU26A*; GabGab, Apra Harbor, epiphytic on algal turf in farmer fish territories, 3 August 2008, *GU44O-F*, 1 September 2008, *GU44P-B*, 28 March 2009, *GU44W-10* and 10 May 2009, *GU44Y-13*; Pete's Reef, Facpi Pt., 7 September 2008, *GU55A-C*. PALAU. Toachel ra Ngel, Ulebsechel I., 13 April 2009, *PW2009-40*. PUERTO RICO: Caja de Muertos Island, 27 December 1985; Enrique Reef, 7 m deep epiphyte on the red alga *Amphiroa* sp., 8 April 1994, *slide #C94-6*. JAMAICA: Sponge Gardens, St Ann, 27 m deep, 19 November 1995, *slide #A96-14*.

Observations:—Colonies (Figs 1–4) are a few cells long, sometimes branched, each cell at the end of a section of tube, from which the next section arose off-center; Fig. 4 suggests at least a temporary septum within the tubes. In Fig. 1 there appear to be cohabitant naviculoids in the tubes; these have not been commonly observed. *Gato hyalinus* cells are broadly oval, slightly narrower at the basal end, apparently with many elongate-lenticular plastids (Figs 1–4), and the cells arranged in the colonies with the narrower pole toward the base. Frustules are also slightly tapered in girdle view (Fig. 4). In acid-cleaned valves in LM (Figs 5, 6), the rimoportulae can be seen, and sometimes a faint sternum, but the striae are too fine to resolve and the valves appear hyaline.

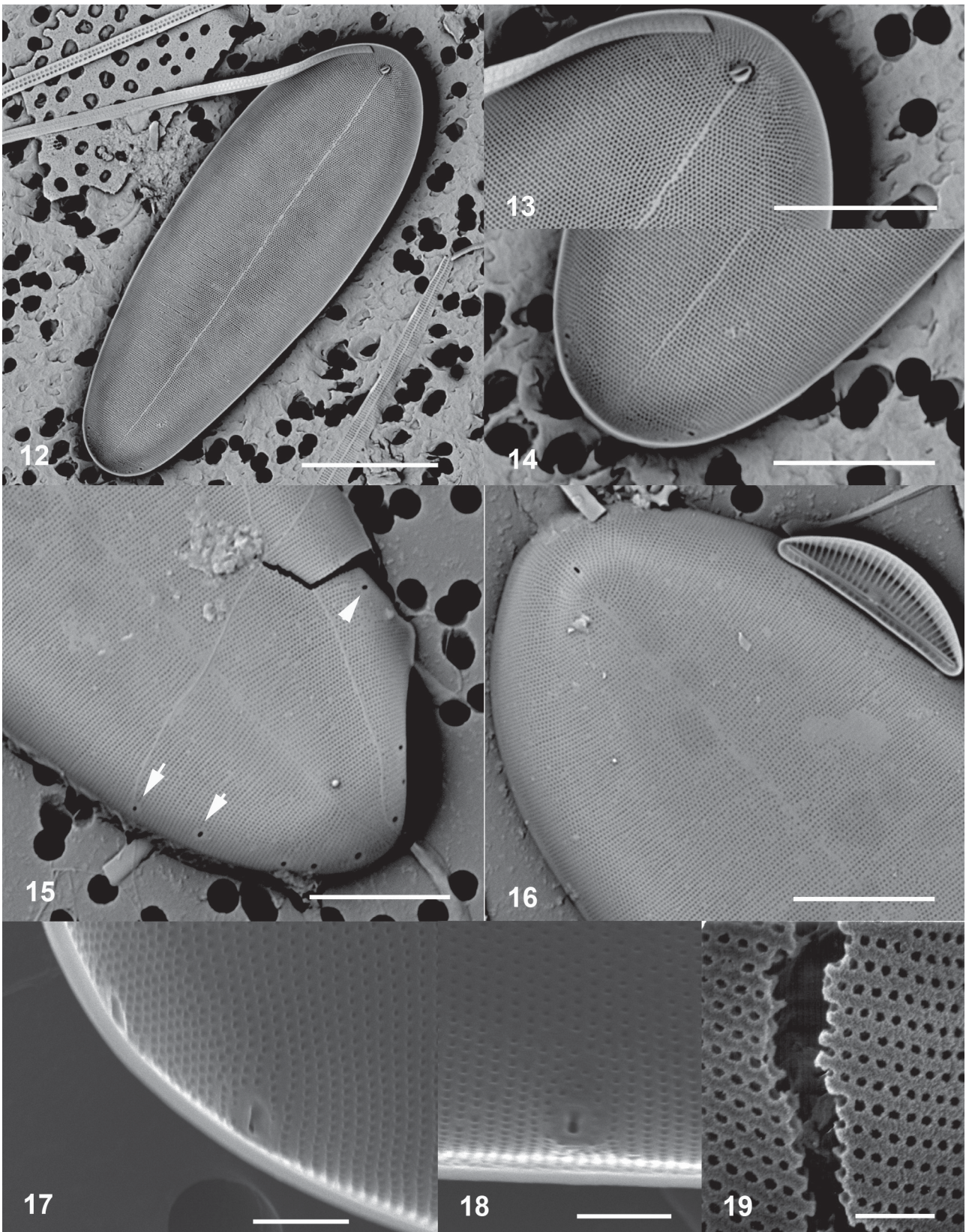


FIGURES 1–6: *Gato hyalinus* light microscopy. Figs 1–4: Live colonies and cells showing mucilage tubes and plastids. Fig. 1. Colony showing branching. A *Striatella unipunctata* cell (*S.u.*) has attached to the end of one tube and there appear to be naviculoid cells inside the tubes (some indicated by arrows). Top part of colony partially overlain by a ribbon of *Hyalosira interrupta* (*H.i.*) (*GU44O-F*). Fig. 2: Dividing cell in near-girdle view at apex of colony, at two focal planes. A *Licmophora* sp. cell (*L.*) is attached to the outside of the tube (*GU44O-F*). Fig. 3: Cell in valve view (*GU44O-F*). Fig. 4: Cells in valve and girdle view with some evidence of a septum (arrow) within the mucilage tube (*GU44W-10*). Figs 5–6: Acid cleaned valves in LM, oriented with basal pole to left. Fig. 5: Valve at two focal planes showing rimoportulae at both poles (arrows) and faint sternum (*GU44Z-15*). Fig. 6: Valve with two rimoportulae (arrows), sternum not visible (*GU44Z-15*). Scale bars: Figs 1–4 = 20 μm ; Figs 5, 6 = 10 μm .

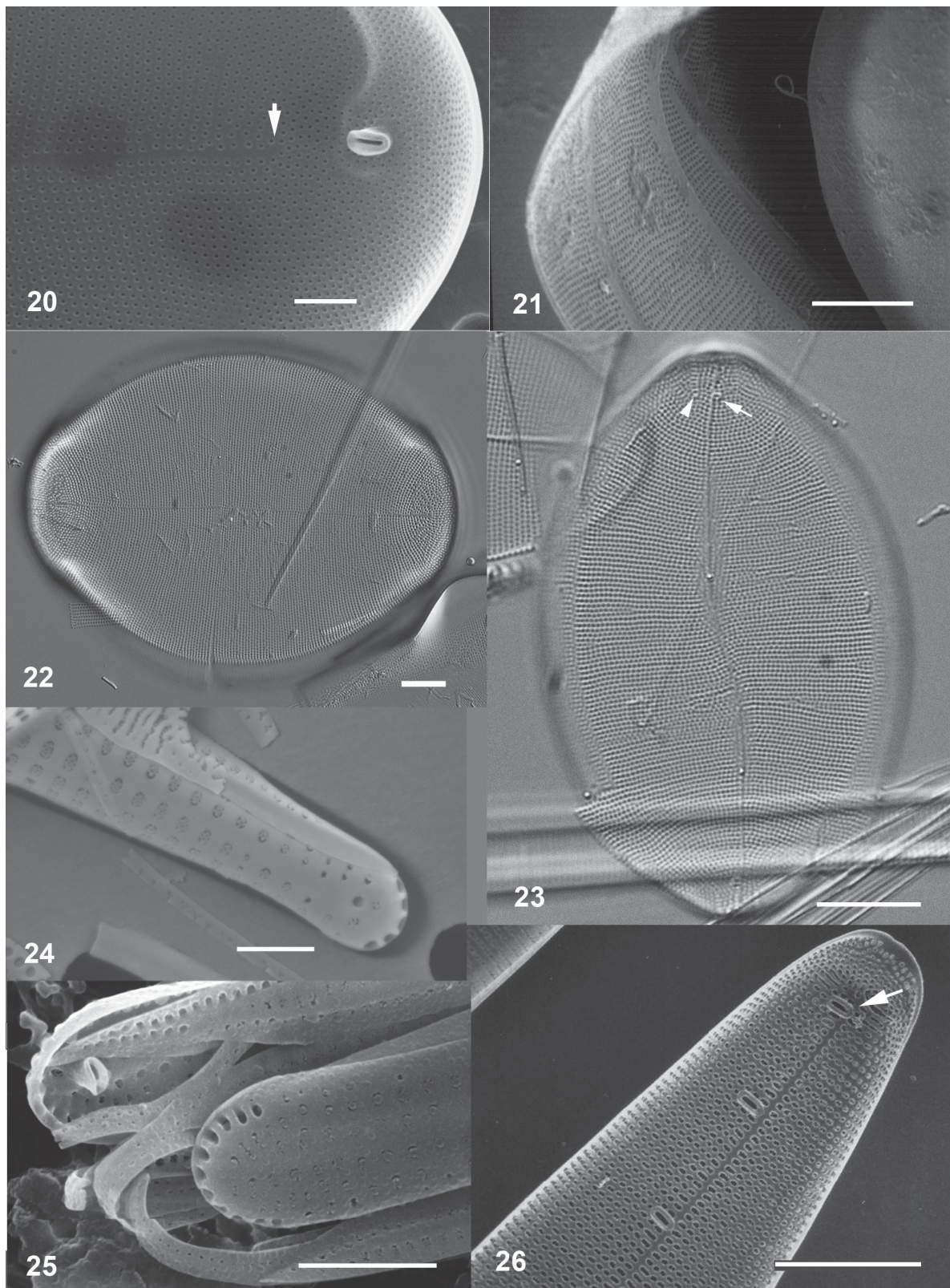


FIGURES 7–11: *Gato hyalinus*, SEM of valves with rimoportula at foot pole. Figs 7, 8: External view of valve and detail of basal pole showing external opening of rimoportula (arrow Fig. 8, also showing apical rimoportula opening, arrow in Fig. 7) and the two rows of rimmed pores with associated oblique striae (“cat’s whiskers”). Fig. 9: Internal view of valve with rimoportulae at both poles (GU44P-B). Figs 10, 11: Details of basal pole with rimoportula in external and internal views (Puerto Rico sample). Scale bars: 7, 9 = 10 μ m; 8 = 5 μ m; 10, 11 = 2 μ m.

In SEM, the valve surface is smooth, with rounded margins, striae 60–70 in 10 μ m consisting of uniseriate rows of simple circular pores (Fig. 19) that extend to the valve border (Figs 7, 8, 10, 11, 20). In places, the pattern could be described as quincunx (e.g., Fig. 13) but the spacing between pores in the striae is generally insufficiently consistent. There is a narrow, irregular break in the striae along the centerline, barely constituting a sternum (Figs 7–16, 20). Striae are parallel except at the head pole, where they radiate from the end of the sternum (Figs 16, 20), and in association with the rimmed pores (Figs 8, 10). Both valves have a small rimoportula at the head pole near the valve apex, at or beyond the end of the sternum (Figs 9, 12, 13, 16, 20), but the two valves are different at the foot pole. There, only one valve of the frustule has a rimoportula and more strongly oblique striae —the “cat’s whiskers” for which the genus is named (Figs 8, 10), the other valve lacks a rimoportula at the foot pole (Figs 12–20). Both foot poles have several large rimmed pores, i.e.,



FIGURES 12–19: *Gato hyalinus*, SEM of valves without rimoportula at foot pole. Figs 12–14: Internal view of valve with rimoportula only at apical pole and detail of basal and apical poles (GU55A-C). Apical detail shows rimoportula at end of sternum. Basal detail shows irregular striae and rimmed pores. Figs 15, 16: External details of basal and apical poles of a valve with no basal rimoportula (GU44Z-15). Fig. 15. Basal pole shows three additional rimmed pores (arrows) interrupting transapical striae. Fig. 16: Apical pole shows rimoportula beyond the end of the sternum within the radiating striae. Figs 17, 18: Internal details of basal and apical poles of a valve with no basal rimoportula (GU44Z-15). Fig. 17: Detail of rimmed pores at the basal pole. Fig. 18: Detail of additional rimmed pore. Fig. 19: Detail of areolae along a fracture through the valve (Puerto Rico sample). Scale bars: Fig. 12 = 10 μ m; Figs 13–16 = 5 μ m; Figs 17, 18 = 1 μ m; Fig. 19 = 500 nm.



FIGURES 20–26: Figs 20, 21: *Gato hyalinus*, SEM. Fig. 20: Head pole showing end of sternum (arrow), radiating striae, and rimoportula (GU44Z-15). Fig. 21: Portion of girdle bands (internal aspect) (Puerto Rico sample). Fig. 22: *Florella portoricensis*, LM, acid cleaned valve (RMI-M1: 5 m deep, Mile 28, Laura, Majuro Atoll, Marshall Islands). Fig. 23: *Florella pascuensis* LM, acid cleaned valve, showing a rimoportula (arrow) and one of the rows of transapical slits (arrowhead) (RMI-J5: 1 m deep reef on Kabbenbock Islet, Jaluit Atoll, Marshall Islands). Figs 24–26: *Licmophora* spp., SEM. Fig. 24: Foot pole of *Licmophora proboscidea?*, external view showing areolae, rimoportula opening, and multiscissura with 5 slits (GU41D-A1). Fig. 25: Foot pole of *Licmophora* sp. showing internal and external details of multiscissura (11 slits) and rimoportula. Note absence of rimoportula on the valve in external view. (Palau specimen.) Fig. 26: *Licmophora flabellata*, internal view of apex showing an apical rimoportula at end of sternum (arrow), plus 2 additional rimoportulae along the sternum (Puerto Rico specimen). Scale bars: Fig. 22, 23 = 10 μ m; Fig. 24 = 5 μ m; Figs 21, 26 = 2 μ m; Figs 20, 25 = 1 μ m.

that have slightly thickened rims internally (Figs 7, 8, 10, 11, 15, 17). There are two series of rimmed pores, typically 4–5 on each side of the foot pole on the valve with a rimoportula; there are only 3 on those without a foot-pole rimoportula. In addition several irregularly placed pores occurred near the foot pole on both valves, interrupting 2 or more striae (Fig. 15, 18), but are not observed near the head pole. On valves with a basal rimoportula there are pairs of oblique striae extending from the sternum to the basal set of rimmed (Figs 7, 8, 10, 11); these are not obvious on valves without a basal rimoportula, where only some irregularity in the striae was observed (Figs 14, 15, 17). We have little information on girdle bands, but they appear to be finely punctate (Fig. 21), similar to the valve surface.

Genera morphologically most similar to *Gato* are *Florella* and *Licmophora*. We do not suggest that either of these is related to *Gato*. Besides Navarro's (1982, 1996, 2002) descriptions, we have observed *Florella portoricensis* Navarro (1982: 248, 258, emend Navarro 1996: 304) (Fig. 22) and *Florella pascuensis* Navarro (2002: 284) (Fig. 23) from the Republic of the Marshall Islands; this is the first confirmed report of these species from that country, and the first confirmed record of *F. portoricensis* from the Pacific Ocean. In addition Lobban *et al.* (2012) observed and cultured samples of *F. pascuensis* from Guam. The valves of *Florella* spp. are isopolar with parallel striae of cribrate areolae continuing unbroken to the valve border from an indistinct sternum; there are no pore fields. *F. portoricensis* has a series of rudimentary rimoportulae at each apex, indistinguishable from areolae except in internal SEM views, whereas *F. pascuensis* has two labiate rimoportulae, one at each end of the sternum, visible even in LM (Navarro 1996, 2002). *F. pascuensis* also has a unique pattern of slit-like areolae at each end.

Frustules of *Licmophora* spp., on the other hand, are heteropolar and heterovalvar. A series of (5 to >30) simple slits at the foot pole is developed into a distinctive multiscissura (Figs 24, 25). The areolae (Fig. 24) are separated by virgae and viminae (Honeywill 1988). Although the rimoportulae of most *Licmophora* species are labiate rimoportulae (Fig. 25), in *L. flabellata* (Carmichael mscr. 1826, according to Agardh) C. Agardh (1831: 41, emend Sar & Ferrario 1990: 404) the head pole rimoportula and the unique series of extra rimoportulae along the sternum lack labia (Fig. 26). These have been characterized by Sar & Ferrario (1990) as “sessile rimoportulae” and are perhaps similar in structure (though not position) to the rimmed pores in *Gato*.

Discussion

Based on morphological criteria *Gato* does not appear close to any known genus of araphid diatoms. *Licmophora* species are an intriguing comparison because, like *Gato*, all are heteropolar, with distinctive structure at the basal pole; many are also heterovalvar with a basal rimoportula on only one valve. Some species of *Licmophora* have a rimoportula at the head pole on both valves, others have only one on the valve that lacks a foot-pole rimoportula. However, while the multiscissura might have a similar function to the series of basal rimmed pores in *Gato*, there is no evidence of homology, and there is no reason to suppose a relationship between *Gato* and *Licmophora*. The general structure of *Florella* is similar to *Gato* and unlike other araphids, but the symmetrical valves and the colony type are not like *Gato*. The most characteristic feature of *Gato* is the series of rimmed pores, for which we can find no parallel. Most araphids have a single rimoportula at one or both poles, but Sar & Ferrario (1990) have shown that *L. flabellata* is an exception. The Florellaceae Navarro (1996: 301) was established on the basis of a single species (now it has two species), and its limits may need emending, but for the time being we leave *Gato* without familial or ordinal assignment.

The tube-dwelling habit of *Gato* is so far unique among araphids, but there is no reason to suppose a correlation between valve structure (e.g., the rimmed pores) and tube formation. While mucilage is often associated with apical pore fields (e.g., *Grammatophora* Ehrenberg (1840: 46), see Sato *et al.* 2008) or distinctive pores (e.g., partectal pores in some *Mastogloia* Thwaites in W. Smith (1856: 63), see Stephens & Gibson 1979; Hein *et al.* 1993), no special structure is present in raphid tube-forming diatoms (Cox 1981; Lobban 1989). Similarly, while stalk secretion in *Licmophora* might be associated with the multiscissura, no

evident structural features at the attachment pole are present in other taxa attached to stalks [e.g., *Mastogloia inaequalis* Cleve (1895: 250) and *M. cuneata* (Meister 1937: 268) Simonsen (1990: 134)– Lobban *et al.* (2012), *Climacosphenia* Ehrenberg (1843: 401) spp., *Ardissonea* De Notaris in De Notaris & Baglietto (1870: no. 334) spp.] or attached by a mucilage pad at one pole [e.g., *Podocystis* spp., *Toxarium undulatum* Bailey (1854: 15)]. Although diatom movement is most often associated with the raphe system, araphid diatoms can also move. For example *Toxarium* J.W. Bailey (1854: 15) cells moved with one pole in contact with the substratum (Kooistra *et al.* 2003) but has no special structures to allow movement.

Gato hyalinus is easily overlooked as a girdle band in acid cleaned samples in LM but on the basis of our records of in the western Pacific and the Caribbean, we expect that it is widespread in the tropics.

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