



A new order and family of diatoms: Arcanodiscales, Arcanodiscaceae (Bacillariophyta) to accommodate *Arcanodiscus platti* gen. nov. et sp. nov. from the Argentinian Patagonia

Nora I. Maidana^{1*}, Eduardo A. Morales², J. Platt Bradbury[†],
Frank Schäbitz³ & Václav Houk⁴

¹ Depto. de Biodiversidad y Biología Experimental, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires; IBBEA (CONICET-UBA), Buenos Aires, Argentina

² Laboratório da Água, Instituto de Ciências da Terra, Universidade de Évora, Rua da Barba Rala No. 1, Parque Industrial de Tecnológico de Évora 7005-345, Évora, Portugal

³ Seminar für Geographie und ihre Didaktik, University of Cologne, Gronewaldstr. 2, 50931 Cologne, Germany

⁴ Institute of Botany, Czech Academy of Sciences, Třeboň, Czech Republic

* Corresponding author: noramaidana@gmail.com

With 19 figures

Abstract: A new diatom, *Arcanodiscus platti* gen. nov. et sp. nov., is described from the Argentinian Patagonia with a novel combination of features. Frustules are robust, strongly silicified, with large and thick central hyaline area and thick valve mantle, under the valve edge often with external parallel undulations. Valves without labiate or strutted processes, the valve mantle areolae internally with rotae; a combination of features that has not been described before. The new taxon is morphologically closely related to several representatives of the genus *Melosira* C.A. Agardh, e.g., *M. robusta* Hustedt (Houk comm.). However, it differs from them by the discoid frustules solitary or forming short filaments, non-loculate, tubular areolae occluded internally by rotae, lacking of processes, but having a single special round aperture, herein termed the portula. Therefore, a new order and family, Arcanodiscales ord. nov. and Arcanodiscaceae fam. nov., are here described to allocate the genus *Arcanodiscus* gen. nov. Morphological details of the new species, based on a combined light (LM) and scanning electron (SEM) microscopy, as well as ecological aspects, are discussed in the light of available information.

Key words: Bacillariophyceae, centric diatoms, lakes, maar lake, Paleolimnology, sediments, South America

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Introduction

Within the framework of the interdisciplinary project “South Argentinian Lake Sediment Archives and Modelling” (SALSA) (Zolitschka et al. 2004), several lakes were studied in the Pali Aike Volcanic Field and the Pampa Alta volcanic plateau, both in southern Santa Cruz Province. In the project, a multiproxy approach combining biological, sedimentological and geochemical data was used to investigate the paleoenvironmental history of southeastern Patagonia during the Quaternary. One of the studied lakes was Laguna Cháltel (also known as Laguna Azul), a crater lake located about 160 km east of the Southern Patagonian Ice Field and about 70 km east of the large proglacial lakes Viedma and Argentino (Fig. 1).

When analyzing surface sediments and core samples from Laguna Cháltel, a heavily silicified centric diatom was observed that could not be identified using combined LM and SEM. A unique

combination of features allows us consider this taxon as new to science at order, family, genus and species levels. Its morphological features as well as ecological aspects are discussed in the context of available information for Laguna Cháltel and for morphologically related taxa.

Material and methods

Study area

Laguna Cháltel (49°58' S, 71°07' W) is situated at 788 m a.s.l. and is a typical circular maar lake with a mean lake diameter of 2.6 km and a current water depth of 41 m. The base of Laguna Cháltel has Miocene sediments and Pliocene TiO₂-rich basaltic lavas assigned to La Siberia and Laguna Barrosa Basalts (Corbella & Lara 2008), part of the discontinuous N-strending belt of Late Pliocene mafic backarc lava formations (D'Orazio et al. 2004). Climate wise, the region is semiarid with cool temperatures and strong Westerly winds, resulting in steppe and semidesert vegetation of tussock grasses (*Stipa* spp.) and *Festuca pallescens* (St.Yves) Parodi as dominant species (Movia et al. 1987, Paruelo et al. 1998, Zolitschka et al. 2006, Garreaud et al. 2009). Regional interpolation (there are no meteorological stations in the area) suggests a mean annual air temperature between 7 °C and 8 °C and a mean annual precipitation around 150 mm (Oliva et al. 2001), with considerable amounts of snow on the Pampa Alta plateau in winter (Ohlendorf et al. 2014).

Vertical, 40 m-high crater walls surround the lake at its present level. The lake has several small inflows, which contribution to the lake is probably highest during snowmelt. There have been recent and past water level changes as evidenced by surrounding vegetation, terraces and carbonate crusts deposited on the shores (Ohlendorf et al. 2014).

Surface water temperature shows a clear seasonal signal with a temperature lower than 1 °C between June/July and September/October and above 8 °C between January and April/May. There are records from March 9, 2004 (Ohlendorf et al., 2014) of slight water column stratification with temperatures of 12.2 °C in the epilimnion (0–2 m water depth) and 10.6 °C in the hypolimnion below a depth of 5 m.

Water chemistry was characterized by a dominance of carbonate ions (mostly HCO₃⁻ at the given pH) and high Na⁺ concentrations. Alkalinity of the surface water was 8.7 mmol L⁻¹. Mean nutrient concentrations also from March, 2004 were 0.14 mg L⁻¹ for nitrate, 0.388 mg L⁻¹ for total phosphorus and 2.28 mg L⁻¹ for silica. Only the latter showed considerable variation through the water column. Oxygen concentrations were between 9.7 mg L⁻¹ in the epilimnion and 7.8 mg L⁻¹ in the hypolimnion. Values of pH ranged from 9.0 to 8.0 in the epilimnion and hypolimnion, respectively. Electric conductance showed values around 788 µS cm⁻¹ throughout the entire profile (Ohlendorf et al. 2014).

Sample collection

Samples studied for the present work came from two sediment cores, collected with an ETH-gravity corer from the center of the lake at 41 m water depth (CHA 04/4; 58 cm in length) and the other located 250 m from the shore at ca. 20 m water depth (CHA 04/5; 98 cm in length).

In addition, surface sediments, collected by dragging near the shore of the lake and fixed immediately after collection with 4% formalin, were analyzed. All samples are currently stored in the Laboratorio de Diatomeas Continentales, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires.

Microscopy

Subsamples of both sediment cores, taken every 1 cm, were processed following standard methods for diatom analysis (Battarbee 1986). Absolute abundances were estimated using the microspheres method (Battarbee & Kneen 1982), and relative abundances were calculated counting at least 400 valves on each permanent slide along random transects. Total diatom

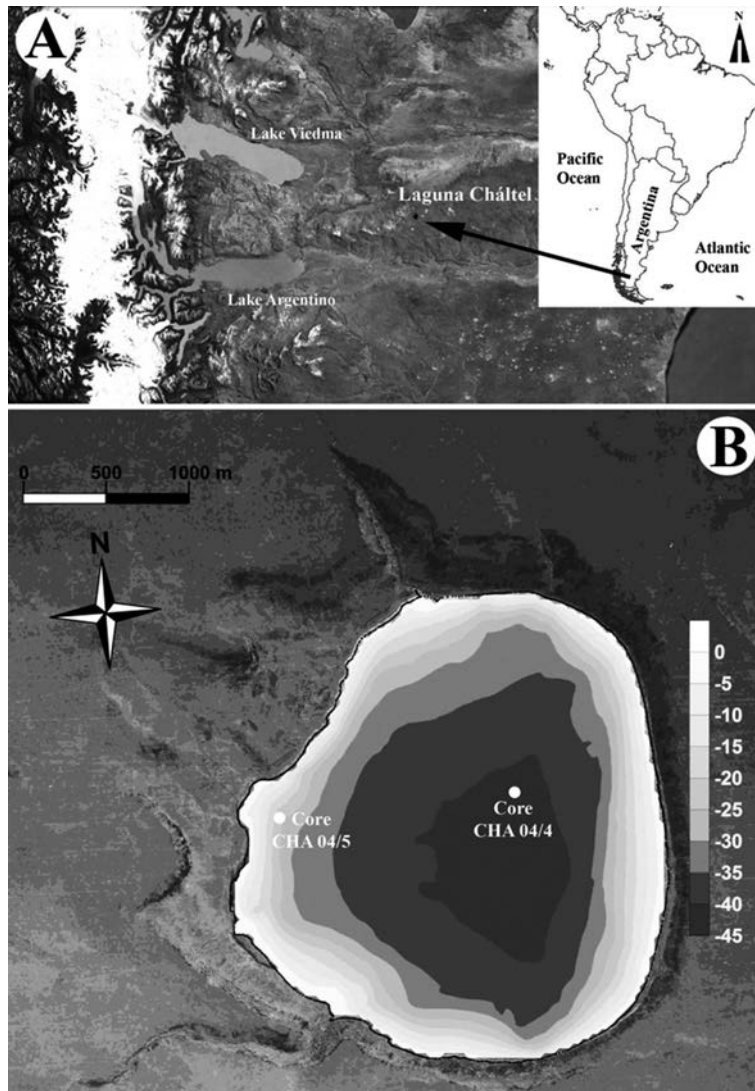


Fig. 1. Localization and bathymetry of Laguna Cháhtel in the Pampa Alta volcanic plateau, Argentinian Patagonia. **A.** Laguna Cháhtel in relation to South America (inset) and proximity to lakes Viedma and Argentino. **B.** Bathymetry showing sites where analyzed cores were collected.

concentrations, the relative abundances of the most important diatoms and biogenic silica (weight percent composition) were plotted using Tilia software (Grimm 1911).

LM observations were made using a Reichert Jung-Polyvar microscope equipped with a PlanApo 100X, NA 1.32, immersion objective and DIC optics. Images were captured with a Canon EOS 600D digital camera mounted directly on the microscope. SEM observations were performed using a Zeiss SUPRA 40 microscope (Centro de Microscopías Avanzadas, FCEyN,

Universidad de Buenos Aires). All SEM images were digitally captured and plates made using Adobe Photoshop CS3.

Measurement of valves was done on both LM and SEM digital images using a Zeiss Axio-vision 4.8.2 software. Morphological terminology follows Round et al. (1990).

Results

Arcanodiscales E. Morales & Maidana ord. nov.

Family Arcanodiscaceae Maidana & E. Morales fam. nov.

Description of Order and Family: Discoid frustules, solitary or in short chains. Plastids unknown. Valves with tubular areolae, with the internal opening covered by rotae. Rimo- and fultoportulae absent. Portulae reduced to simple round openings, internally opened on a prominence and arranged on a ring near the abvalvar edge of mantle. Girdle elements numerous and closed. Thriving in moderate to high conductivity water habitats.

Typus for Order and Family: *Arcanodiscus* Maidana & E. Morales gen nov.

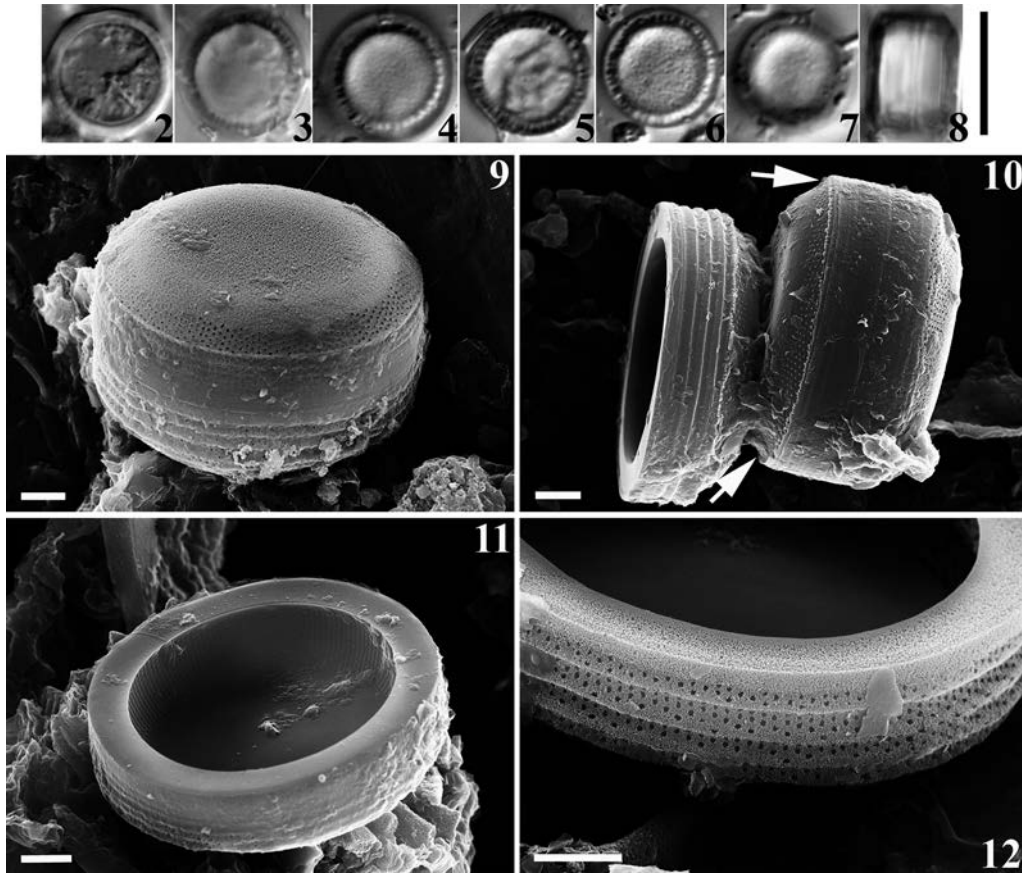
Genus *Arcanodiscus* Maidana & E. Morales gen. nov.

Description: Frustules discoid, solitary or in short chains. Valves with flat and solid hyaline central area and a thicker mantle, the latter with faint radial lines corresponding to the mantle tubular areolae. Striae continuous from valve face margin to mantle. Areolae disposed in a quincunx arrangement, internally covered by rotae. Gradual or abrupt transition between valve face and mantle. Mantle bearing parallel undulations upon which the girdle elements rest. Rimo- and fultoportulae absent, but a reduced type of portula with an internal opening situated on a prominence and a simple external opening, forms a submarginal ring at the abvalvar portion of the mantle. Cingulum composed of numerous, thin, closed elements, each with a row of perivalvally-elongated poroids.

Generitype: *Arcanodiscus platti* sp. nov. Maidana & E. Morales

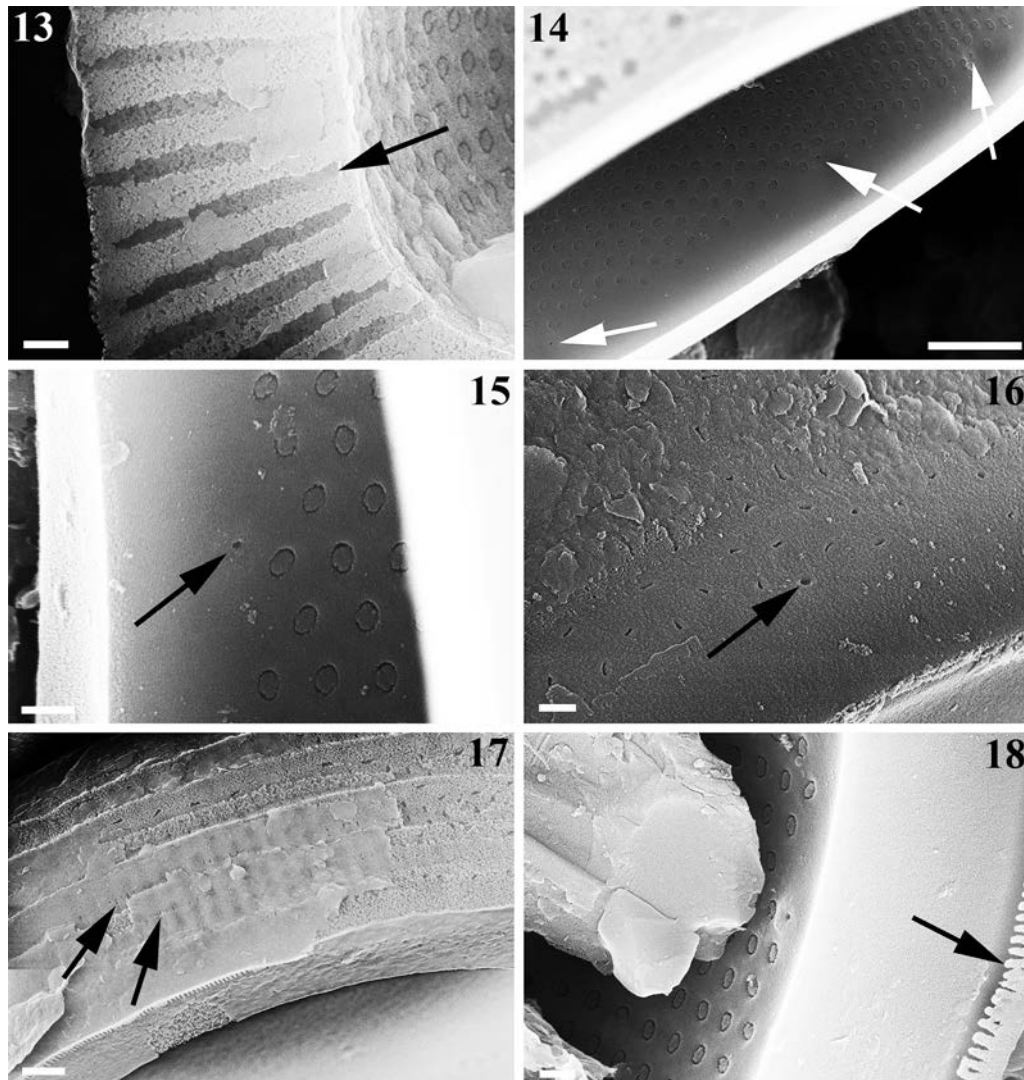
***Arcanodiscus platti* Maidana & E. Morales sp. nov.**

Description: LM: Frustules discoid, solitary or in short chains (2–3 cells), joined by a cementing substance (Fig. 8). Valves robust, heavily silicified, with thick mantle with a flat hyaline central area bearing no visible processes (Figs 2–6). Valve face diameter 12.5–16 μm ($14.40 \pm 0.81 \mu\text{m}$, $n = 32$). Valve mantle abvalvar border (silicified ring) representing 10–12% of the valve diameter, in LM with faint radial lines (Figs 3–6). In girdle view, mantle indistinguishable from the cingulum, although in some cases concentric marks left by girdle bands on mantle visible (Fig. 8). SEM: Frustules discoid with perivalvar axis approximately 8.4–10.9 μm long ($9.27 \pm 1.09 \mu\text{m}$; $n = 4$) (Figs 9–10). On the valve face, very wide central zone free of ornamentation present (larger than 80% of the valve diameter), with perforated peripheral zone (Figs 9, 11). Striae approximately 3–5 (4.1 ± 0.5) in 1 μm ($n = 11$), continuous from valve face to mantle and ending shortly before the abvalvar border of the valve mantle (Figs 9, 10). Areolae in regular rows, but concentrically forming a quincunx arrangement (Figs 9, 14–15), 3–5 (4.2 ± 0.5) areolae in 1 μm ($n = 11$). Areolae narrowly tubular, with roundish openings in both internal and external views (Figs 11–15). Externally, apparently no occlusions present. Individual areolae directly opening to the outer side (Figs 9, 11). Internally, each areola with a rota, probably internally attached to the walls of the areolae (Figs 13–15). Umbilicus-like central zone formed by a massive, solid, silicified plate (10.3–12 μm), thicker at the valve center (Fig. 12). Transition between valve face and mantle gradual and indistinguishable, or with a small concave “step” at the valve face border before an abrupt fall onto the mantle (Figs 9–10). In some cases, both conditions present in the same frustule (Fig. 10). External surface of the valve mantle flat or with a series of parallel undulations, normally covered by girdle elements (Figs 10–12). Thickness of



Figs 2–12. LM and SEM images of *Archanodiscus platti* sp. nov., type population. **2–8.** LM images. 2–6. Focus on the valve mantle edge visible as a thick ring. 7. Focus on valve face, showing hyaline area with spots and granulations due to deposition of mineral material. 8. Girdle view. **9–12.** SEM images. 9. Tilted view of complete frustule showing the large hyaline central area, the transition of valve face to mantle, and the valve mantle partially covered by the cingulum. 10. A complete frustule with a valve still attached by cementing substances. Notice the parallel undulations in the valve mantle. Arrows point to the “steps” at the valve face border. 11. Broken piece of a valve showing the solid, unornamented hyaline area and the tubular nature of the areolae on the valve face margin and mantle. 12. Detail of mantle showing external round openings of areolae and their arrangement. See also the parallel undulations upon which rest the girdle elements. Scales, 2–8: 10 μm ; 9–12: 2 μm .

abvalvar border of mantle 0.8–1.9 μm . Internally, submarginal ring of perforated protuberances at the abvalvar portion of the mantle visible, irregularly disposed every 9–16 striae (Figs 14, 15, 18). Inner openings of these portulae unoccluded, round and smaller than the areolar openings, and are located above or below the limit of the striae at the abvalvar portion of the mantle (Figs 14, 15, 18). Externally, the openings are also round, difficult to see in uneroded valves since they are covered by the cingulum (Figs 16–17). Cingulum composed of closed, isomorphic, very thin and slightly silicified elements, each with a single row of perivalvally-elongated perforations (Fig. 17). Pars interior of valvocopula fimbriate (Fig. 18).



Figs 13–18. SEM images of *A. platti* sp. nov., type population. **13.** Broken piece of a valve showing tubular structure of the areolae at the mantle (arrow). Notice absence of alveoli or bullulae. **14.** Detail of inner areolation pattern with rota-like occlusions and a series of portulae on a prominence (arrows), located within the striae line at the abvalvar mantle margin. **15.** Detail of a portula (arrow) located beyond the striae line. **16.** Detail of outer abvalvar mantle edge, still covered by remains of the girdle elements, showing the external round opening of a portula (arrow). **17.** External detail of mantle showing remains of the thin girdle elements. Arrows point to the single, transapically-elongated poroids on two contiguous bands. **18.** Detail of the valvocopular fimbriae attached to the external edge of the mantle base (arrow). A portula and the rota-like internal occlusions of the areolae can also be seen. Scales, 13–16, 18: 200 nm, 17: 600 nm; 14: 1 μ m.

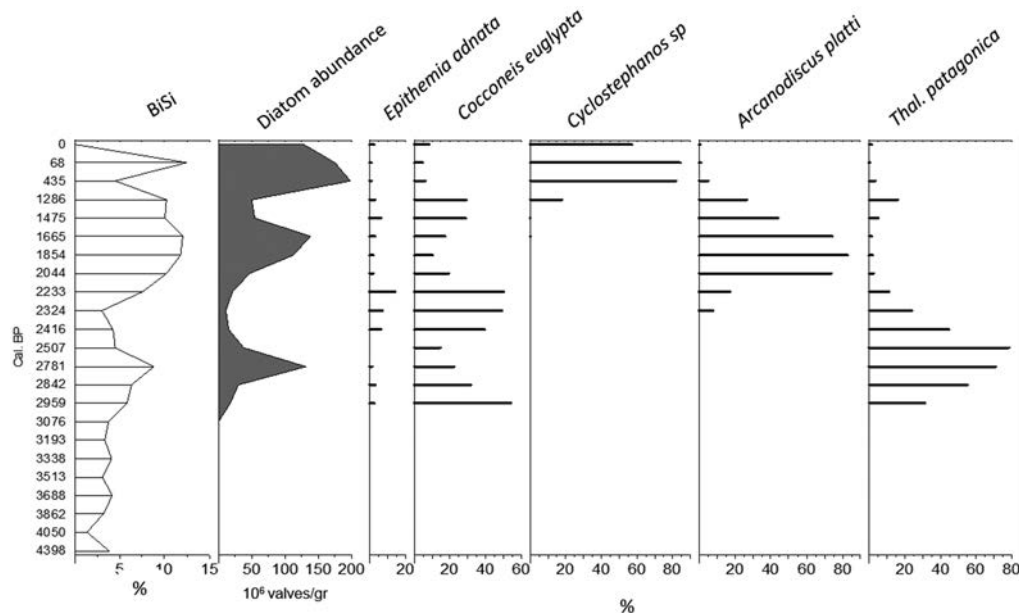


Fig. 19. Record of biogenic silica (BiSi), total diatom abundance and relative abundance of selected taxa, including *A. platti*, along the studied sedimentary sequence (core CHA 04/4) in Laguna Cháltel since 4398 cal yrs BP

Holotype: Population in slide CHA 04/4 6–7 cm (LPC 15218), deposited in the Colección of División Ficología “Dr. Sebastián a. Guarrera”, Herbario del Museo de Ciencias Naturales, Universidad Nacional de La Plata. Partially illustrated here in LM as figs 5–7. Leg. Salsa project (<http://www.salsa.uni-bremen.de/home.html>), 2004.

Isotype: BA 49155 Herbario de Plantas Celulares, Museo ACrgentino de Ciencias Naturales “Bernardino Rivadavia”.

Type locality: Laguna Cháltel (49°58' S, 71°07' W), Santa Cruz Province, Argentina

Etymology: Dedicated to the memory of Dr. J. Platt Bradbury (1936–2005), with whom the senior author found *A. platti* in Lago Cardiel for the first time.

Habitus: Probably periphytic due to its heavily silicified frustule and to the autecology of accompanying diatom flora; growing solitary or in 2–3 cells chains.

Autecology: In waters with moderate to high conductivity.

Distribution: Currently the diatom has only been reported from the type locality and from Lago Cardiel (48°48.59' S, 71°13' W), also located in the Argentinian Patagonia (see discussion). In Laguna Cháltel, the relative abundance of *A. platti* reaches up to 86% of the total diatom community found in each preparation in both cores subsamples. Between 2324 and 1286 cal BP its abundance oscillates between 23–86%, and within that period the accompanying taxa are *Cocconeis euglypta* Ehrenberg (11–29%), *Thalassiosira patagonica* Maidana (1.5–16%) and *Epithemia adnata* (Kützing) Brébisson (2–6.5%) (Fig. 19).

Discussion

In the core taken at the lake center, *Arcanodiscus platti* sp. nov. appears at ca. 2400 cal yrs BP and its abundance is drastically reduced after ca. 1290 cal yrs BP. The decrease in abundance coincides with an increase in the abundance of planktonic species, mainly represented by an undescribed species of *Cyclostephanos* F. E. Round (Maidana et al. 2016 in prep.). The maximum abundance of *A. platti* occurred when diatom concentration in Laguna Cháitel was at a high, and the biogenic silica values were the highest on record for the lake (Fig. 19; Ohlendorf et al. 2014). This might be supplied by the heavily silicified valves of this new centric diatom.

This new taxon was not found alive in the surface sediment samples. In these samples, this diatom was always found as isolated valves or empty frustules and in very low abundance, representing less than 0.50% of the total diatoms.

The small, undescribed species of *Hyalodiscus* Ehrenberg reported by Markgraf et al. (2003) in two cores obtained from Lago Cardiel corresponds to the diatom described as new in this manuscript (confirmed by the senior author). The diatom occurred along the entire core, but dominated the interval from 950 cm to 750 cm (9600 to 6800 BP) of core CAR-98-2L. Markgraf et al. (2003) stated that the diatom was found as an uncommon representative between 15 m and 20 m depth in the sediments of the same lake. They further speculated that it “probably lives loosely attached to available substrates within the lower part of the photic zone, but may enter the plankton if turbulence is sufficient.”

The taxon described herein has a unique set of features that places it apart from any known diatom order, family or genus. The large central hyaline area and the lack of bullulae in this region, the thinner hyaline area compared to the thickness of the valve face/mantle junction, the lack of labiate or strutted processes, the areolae rota-like occlusion located on the internal valve surface, and the marks left by the cingulum on the valve mantle, have not been observed in any given centric.

This combination of features is most proximate to those of the Melosirales R. M. Crawford in Round, Crawford & Mann (1990). As defined by Round et al. (1990), representatives of the Melosirales have spherical to cylindrical frustules forming long chains and having discoid plastids. The way in which contiguous frustules unite can be by tubular projections, spines or by mucus secretions. Areolae are loculate with rota or porous hymens covering the areolae and with dissimilar internal and external openings. Rimoportulae are not well-developed, aggregated or dispersed. Girdle elements are numerous and open. They live in saline, brackish and freshwater. *Arcanodiscus platti* has discoid frustules, joining by a cementing substance, but chains are very short. Plastids are unknown in this taxon. Valves have tubular areolae with round internal and external openings. Internal openings are slightly wider than the external ones, and they are covered by a rota-like occlusion. There are no known processes. Girdle elements are closed and numerous. The taxon is reported so far from brackish inland waters. Based on these differences a new Order within the Coscinodiscophycidae is required, order that we herein describe as *Arcanodiscales* ord. nov.

At the family and the genus level, it is also clear that *A. platti* is not related to the family Hyalodiscaceae containing *Hyalodiscus* and *Podosira* Ehrenberg, or the family Melosiraceae containing *Melosira* C. A. Agardh.

Hyalodiscus is distributed in marine- to freshwaters and the frustules of its species are lenticular, with the hyaline central area less extended than in *Arcanodiscus* which is a freshwater diatom, with discoid frustules. The only species that had an umbilicus occupying a bit more than 50% of the valve diameter is *H. lentiginosus* J. John (John 1982). *Hyalodiscus* has bullulae sandwiched between internally and externally closed areolar foramina. The bullulae are also present in the areolated valve face and mantle. The rimoportulae in *Hyalodiscus* occur in a ring at a certain distance along the valve mantle edge and also scattered over the rest of the mantle and valve face (Round et al. 1990). Species of *Hyalodiscus* have a cingulum composed of closed elements perforated by a single row of roundish poroids (Rott et al. 2009). *Arcanodiscus platti*

sp. nov. has a larger umbilicus-like central area, non-bullulate areolae, the poroids in the girdle bands groove-like, transapically elongated, and there are no rimoportulae.

In turn, *Podosira* is marine, has spherical to subspherical frustules, loculate, non-bullulate areolae, numerous rimoportulae, the girdle elements are open, and with the exception of the valvacopula, they have a single row of roundish poroids (Round et al. 1990). *Arcanodiscus platti* sp. nov. is so far found in freshwater environments, has discoid frustules, tubular areolae, lacks rimoportulae, and all girdle elements perforated by a single row of transapically-elongated poroids. Furthermore, *Podosira* species have an abvalvar edge that is hollow, while in *A. platti* this mantle edge is solid.

Melosira, on its part, lives in marine to freshwater habitats and has subspherical to cylindrical frustules forming long chains. The entire valves are loculate, with locules open to the exterior by small simple pores and the interior openings covered by rotae. The rimoportulae occur in a row near the abvalvar mantle edge, but also scattered through the valve, or even grouped on the valve face. The cingulum is composed of open, multiareolated and ligulated girdle elements. *Arcanodiscus platti* sp. nov. has discoid frustules, the areolae are distributed only on the valve face margin and the mantle, it does not have rimoportulae and the cingulum is composed of closed girdle elements.

Therefore, a new family is required to accommodate *Arcanodiscus* gen nov., with its only known species thus far, *A. platti* sp. nov. This family is described herein as Arcanodiscaceae fam. nov.

A literature search revealed that the morphologically most similar diatom to *A. platti* sp. nov. was presented in Van de Vijver et al. (2002: 61, pl 2, figs. 1–9, pl. 3, figs. 15–16), who illustrated and described a population from the Crozet Archipelago Subantarctica under the name “*Melosira* aff. *guillauminii* Manguin ex Kociolek & Reviere”. Both taxa have similar valve diameter and striae density, but the main differences are the shape and construction of the frustules. The valves of *M. aff. guillauminii* resemble *A. platti* sp. nov. inasmuch as they possess a central zone at the valve face, free of striae and a delicately perforated marginal zone. However, the central zone in *M. aff. guillauminii* (based on SEM images provided by Van de Vijver et al. 2002) occupies half of the valve face diameter, while in *A. platti* sp. nov. it constitutes more than 80% of the valve diameter. In *A. platti* sp. nov., they are heavily silicified and discoid, with a perivalvar axis shorter than the valve diameter (0.5–0.7:1). In *M. aff. guillauminii*, on the contrary, frustules are noticeably less silicified and have a cylindrical shape, with a perivalvar axis that is longer than the valve diameter (1.6–1.7:1, calculated from figures provided by Van de Vijver et al. 2002). Unfortunately, internal views and details of processes of *M. aff. guillauminii* were not provided by the authors, making it impossible to determine further (di)similarities with *A. platti* sp. nov. or if *M. aff. guillauminii* truly belongs in *Melosira*.

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