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Recibido: 27 de septiembre 2023 - **Aceptado:** 15 de febrero 2024 - **Publicado:** 12 de junio 2024

Para citar este artículo: Cecilia Rodríguez Amenábar, Alessandra Santos, & G. Raquel Guerstein (2024). A new Campanian dinoflagellate cyst from Antarctica: a biostratigraphic and paleoecological key species. *Publicación Electrónica de la Asociación Paleontológica Argentina* 24(1): 199–216.

Link a este artículo: http://dx.doi.org/10.5710/PEAPA.15.02.2024.487

ISSN 2469-0228

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ARTÍCULO Año 2024 - 24(1): 199–216
Publicación Electrónica
ASOCIACIÓN PALEONTOLÓGICA ARGENTINA

A NEW CAMPANIAN DINOFLAGELLATE CYST FROM ANTARCTICA: A BIOSTRATIGRAPHIC AND PALEOECOLOGICAL KEY SPECIES

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Abstract. Palynological analysis of Upper Cretaceous marine rocks from the Rabot and Snow Hill Island formations, James Ross Basin, northeastern Antarctic Peninsula, has revealed the record of a previously undescribed dinoflagellate cyst species, previously assigned to *Oligosphaeridium* sp. A. Here, we provide a formal description of this new species, which we name *Stiphrosphaeridium sobralii* sp. nov. and we add some features to the description of the genus *Stiphrosphaeridium*. The new species is found in Campanian strata, which are calibrated with magnetostratigraphic data. It is considered an important Late Cretaceous biostratigraphic marker commonly recorded in offshore environments of Antarctica.

Key words. Marine Palynology. Offshore Paleoenvironments. Biostratigraphy. Late Cretaceous. James Ross Basin. Antarctic Peninsula.

Resumen. UN NUEVO QUISTE DE DINOFLAGELADO DEL CAMPANIANO DE ANTÁRTIDA: UNA ESPECIE BIOESTRATIGRÁFICA Y PALEOECOLÓGICA CLAVE. El análisis palinológico de rocas marinas del Cretácico Superior de las formaciones Rabot y Snow Hill Island, Cuenca James Ross, noreste de la Península Antártica, ha revelado el registro de una especie de quiste de dinoflagelado no descrita previamente, asignada anteriormente a *Oligosphaeridium* sp. A. Proporcionamos una descripción formal de esta nueva especie, que denominamos *Stiphrosphaeridium sobralii* sp. nov. y agregamos algunos rasgos al género *Stiphrosphaeridium*. La nueva especie proviene de niveles campanianos, los cuales están calibrados con datos magnetoestratigráficos. Se considera un importante marcador bioestratigráfico del Cretácico Tardío comúnmente registrado en ambientes de *offshore* de la Antártida.

Palabras clave. Palinología marina. Paleoambientes de *offshore*. Bioestratigrafía. Cretácico Tardío. Cuenca James Ross. Península Antártica.

The James Ross Basin, located northeast of the Antarctic Peninsula, contains one of the most complete and extensive marine sedimentary sequence in the Southern Hemisphere. The almost continuous deposition of over 6,000 m of Jurassic to Eocene marine sediments makes it a world reference section (Pirrie *et al.*, 1997a). The highly fossiliferous basin has been extensively studied over the last 40 years. Sedimentological studies have been carried out by Ineson *et al.* (1986), Macellari (1988), Scasso *et al.* (1991), Pirrie *et al.* (1997a), Crame *et al.* (2006), Olivero *et al.* (2008), and Olivero (2012), among others. Furthermore, there are several contributions about fossil megafauna (mainly ammonites and vertebrates, Olivero, 2012; Reguero *et al.*, 2022 and references therein) and, to a lesser extent, micropaleontological and palynological assemblages (Dettman & Thompson, 1987; Keating, 1992; Smith, 1992; Sumner, 1992; Wood & Askin, 1992; Scasso *et al.*, 2020; Silva *et al.*, 2023; for further references see Amenábar *et al.*, 2014) as well as palynofacies (Rodríguez Brizuela *et al.*, 2007; Carvalho *et al.*, 2013).

It should be noted that palynomorphs (pollen, spores, dinoflagellate cysts, and other organic-wall remains of microorganisms) can be recovered from marine deposits in large numbers and with high taxonomic diversity. Palynological research in Antarctica is promising because of the abundance of palynomorphs found in most of the sedimentary units and the usefulness of this microfossil group for biostratigraphic and paleocological studies.

The earliest palynological studies of the Antarctic Peninsula area include preliminary analysis of pollen, spores, and dinoflagellate-cyst assemblages of the Upper Cretaceous sediments from the northwest of James Ross, Vega, and Marambio (=Seymour) Islands (Cranwell, 1966; Askin, 1983; Dettmann & Thomson, 1987). These studies highlighted the palynological productivity of the entire region, the potential of palynomorphs for local and regional correlation, and the utility of such data for understanding the paleogeographic evolution of the southern South Atlantic Ocean.

Subsequent palynological studies were summarized in a special issue of Antarctic Science (Volume 4, issue 3), which analyzed numerous localities on James Ross and Vega Islands (Keating, 1992; Keating *et al.*, 1992; Smith, 1992; Sumner, 1992; Wood & Askin, 1992; among others). These contributions have laid the bases for palynological analysis, particularly by describing several Antarctic species.

Such studies have shown that many Antarctic species are also found in Australian and New Zealand assemblages (Raine, 1984; Helby *et al.*, 1987; Raine & Schiøler, 2012). However, some species whose records are restricted to Antarctica, have been left in an open nomenclature. Paramount for this paper is the Antarctic species *Oligosphaeridium* sp. A of Sumner (1992), which was documented from the Upper Cretaceous of Ekelöf Point (southern James Ross Island). The author did not assign it as a new species, possibly because of the scarcity of specimens, which were insufficient to exhibit all the diagnostic characteristics. Later, Pirrie *et al.* (1997a) only illustrated *Oligosphaeridium* sp. A (henceforth, whenever this species is mentioned, it will be referring to the one defined by Sumner, 1992) from the Upper Cretaceous successions at the Ekelöf Point, Redshaw Point (Hamilton Norte *sensu* Olivero, 2012) and Hamilton Point (southern James Ross Island). More recently, Caramés *et al.* (2016) reported the presence of *Oligosphaeridium* sp. A at Ekelöf Point and listed it alongside other palynomorphs. In recent years, the Instituto Antártico Argentino (IAA) has carried out extensive fieldwork on the Antarctic Peninsula area, sampling the Upper Cretaceous successions and allowing a comprehensive study of the palynological assemblages of the southeastern localities of James Ross Island.

Analyses of samples from James Ross Island resulted in the recovery of further specimens of *Oligosphaeridium* sp. A allowing us to describe this species for the first time.

This paper aims to describe and illustrate a new dinoflagellate cyst species from Upper Cretaceous localities in the southeast of James Ross Island. The biostratigraphic range of the species, its geographic distribution, and environmental affinities are also evaluated.

GEOLOGICAL SETTING

The James Ross Basin is a back-arc basin in the northeastern Antarctic Peninsula, approximately 65° S, 74° W. Its extensive and well-exposed Mesozoic and Paleogene marine sedimentary rocks have a thickness of more than 6 km (del Valle *et al.*, 1992). Outcrops are scattered across the eastern of the Antarctic Peninsula and on James Ross, Vega, Humps, Cockburn, Marambio (=Seymour) and Cerro Nevado (=Snow Hill) islands (Olivero, 2012). On James Ross Island, almost all Cretaceous sediments are scattered outcrops around coastal and low-topography areas (Fig. 1). Campanian–lower Maastrichtian sedimentary rocks are well-exposed at Ekelöf Point, Rabot Point, Hamilton Norte (*sensu* Olivero, 2012; or Redshaw Point *sensu* Pirrie *et al.*, 1997a), Hamilton Point, and Redonda Point (Lirio *et al.*, 1989; Pirrie *et al.*, 1997a).

At Ekelöf Point (Fig. 1), southeast of James Ross Island, the Hamilton Point Member of the Santa Marta Formation by Pirrie *et al.* (1997a) was assigned to the Late Cretaceous. Later on, Olivero (2012) considered the Hamilton Point Member to be part of the overlying Snow Hill Island Formation.

The Hamilton Point Member (southeast James Ross Island, Fig. 2) is laterally equivalent to the Gamma Member (northwest James Ross Island, Fig. 2) of the Snow Hill Island Formation (Olivero, 2012), exposed at Santa Marta Cove and Dreadnought Point (Fig. 1). At Ekelöf Point, the Hamilton Point Member, which is approximately 45 m thick, consists of lightly laminated to massive clayey siltstones, vitric and vitric-crystalline tuffs (Caramés *et al.*, 2016). This member would have been formed by the decantation of suspended fine-grained particles with occasional ash fall from a volcanic arc, representing a quiescent environment below the storm wave base between the outer shelf and slope (Robles Hurtado *et al.*, 1997). It has been interpreted to consist of transgressive offshore mudstone deposits (Olivero, 2012).

Based on dinoflagellate cysts (Sumner, 1992), pollen and spores (Pirrie *et al.*, 1997a), ammonites (Olivero, 2012), and foraminifera (Caramés *et al.*, 2016), the age of this member was considered to be late Campanian–early Maastrichtian, in agreement with Olivero (2012), who included the Hamilton Point Member in the NG sequence, one of the three major sedimentary cycles that he identified in the Marambio Group of the James Ross Basin. In recent years, Milanese *et al.* (2019) based on Gradstein *et al.* (2012) timescale, identified the Magnetochron C32/C33 boundary (late Campanian) at the upper part of the Hamilton Point Member (Fig. 2). This boundary has not changed in the updated timescale of Gradstein *et al.* (2020).

Scattered Cenozoic diamictites are also exposed at Ekelöf Point, which overlie Upper Cretaceous deposits and are usually overlined by the basalts and volcaniclastic rocks of the Neogene James Ross Island Volcanic Group (JRIVG)

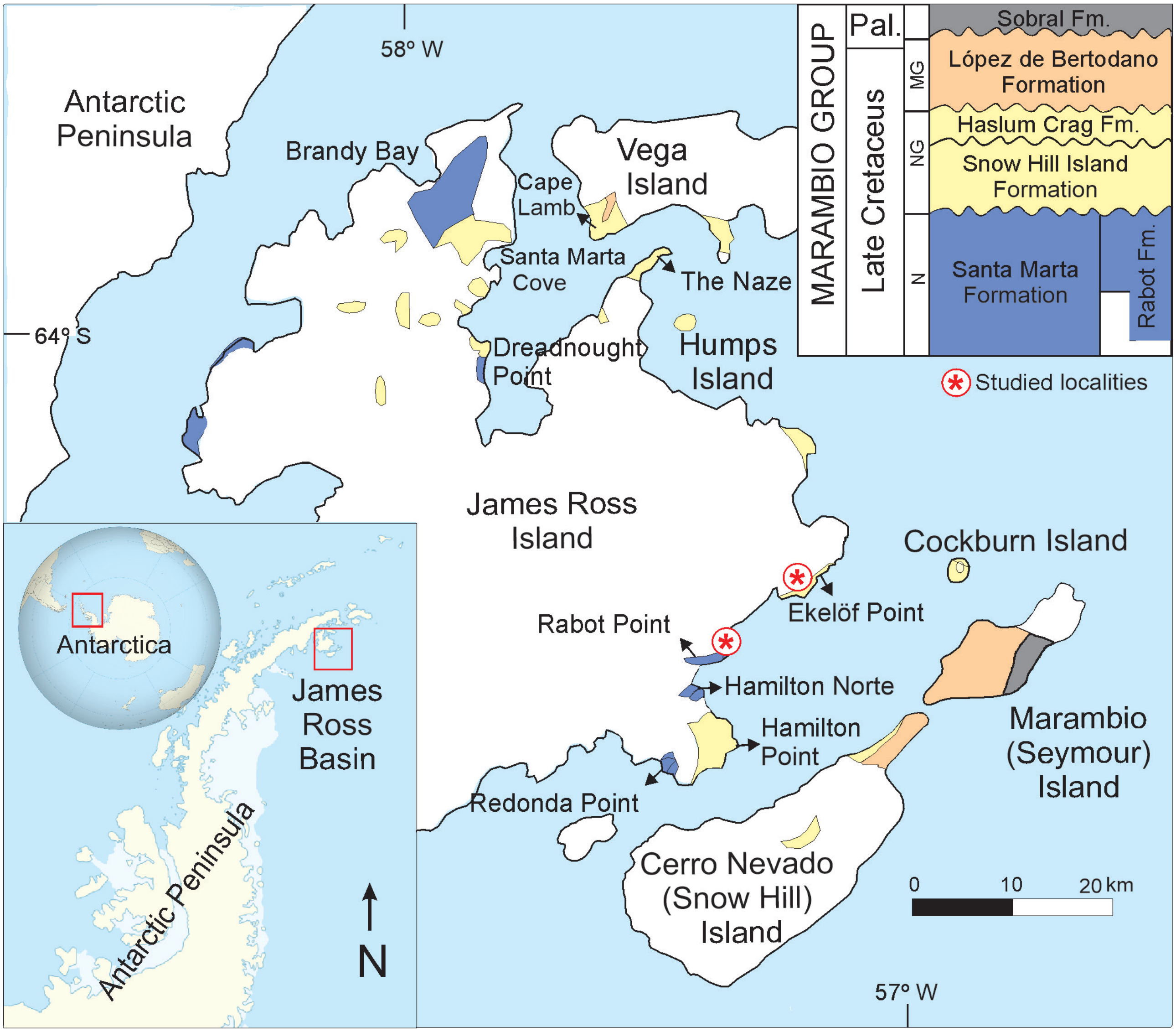

Figure 1. Geological outline of Cretaceous–Paleogene units from the Marambio Group, James Ross Basin, eastern Antarctic Peninsula (after Olivero, 2012 and Milanese *et al.*, 2019). The studied localities are marked with an asterisk. Abbreviations: **N,** (Santonian–early Campanian), **NG,** (late Campanian–early Maastrichtian), and **MG,** (early Maastrichtian–Danian) sequences of Olivero (2012); **Pal,** Paleogene.

(Nelson, 1975; Smellie *et al.*, 2008; Bertoa del Llano *et al.*, 2021). The Ekelöf Point diamictites belong to more than one stratigraphic unit, but are currently assigned to either the Hobbs Glacier Formation (Pirrie *et al.*, 1997b) or the Gage Formation (Lirio *et al.*, 2003). They were deposited as debris flows in subaerial and subaqueous environments, the latter presumably close to the grounding-line of marine-terminating glaciers (Nelson *et al.*, 2009). The age of 3.52 My for the diamictites is derived from the ^{87}Sr/^{86}Sr dates of pectinid shells of *Austrochlamys* sp., while the ^{40}Ar/^{39}Ar dates from the underlying and overlying basaltic lavas of JRIVG at Ekelöf Point yielded isotopic ages of 2.5, 2.8 and 4.0 My (Smellie *et al.*, 2006, 2008; Salzmann *et al.*, 2011).

In the southernmost part of James Ross Island (Fig. 1), the Upper Cretaceous marine sedimentary rocks are assigned to the Rabot Formation, which is 350 m thick at its type locality, Rabot Point (Lirio *et al.*, 1989). Lirio *et al.* (1989) divided Rabot Formation into three informal lithological members: I (lower), II (middle) and III (upper). These members roughly correspond to the informal mapping units a, b,

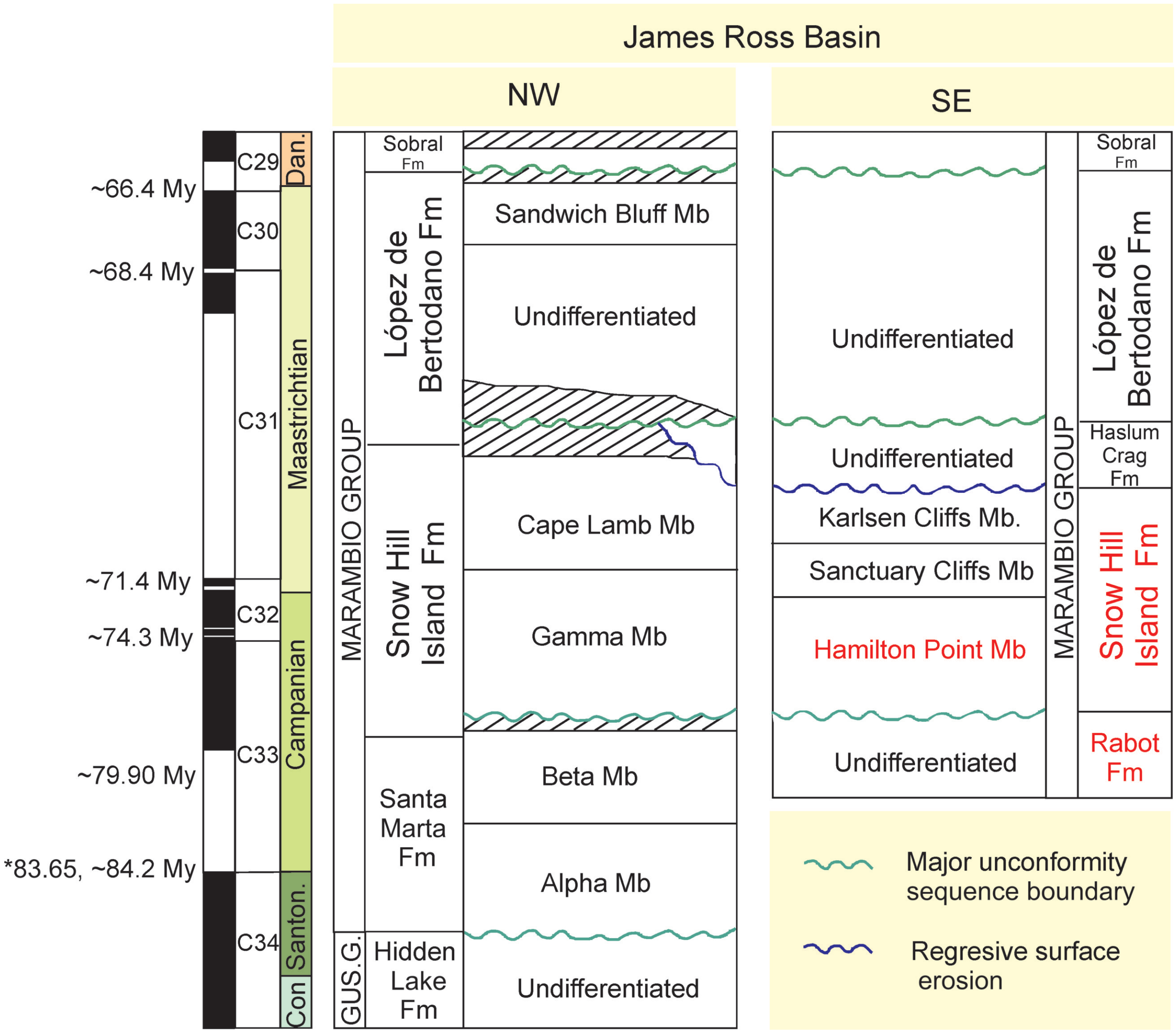

Figure 2. Chronostratigraphy of the Marambio Group and upper Gustav Group after Milanese *et al.* (2020). Reference polarity timescale from Ogg *et al.* (2016). Note differences in the naming of formations and their members between the NW and SE James Ross Basin. Red text indicates the units from which the material under study is derived. The ages of ~79.90 and ~84.2 My are taken from Milanese *et al.* (2017) and their positions in this figure are tentative. *Updated age (83.65 My) according to Gradstein *et al.* (2020). Abbreviations: **Con,** Coniacian; **Santon,** Santonian; **Dan,** Danian; **GUS. G.,** Gustav Group.

and c of Pirrie *et al.* (1997a), which are recognized in the type locality. Member I is exposed only at Rabot Point, whereas members II and III are exposed at the type locality and also at Hamilton Norte (*sensu* Olivero, 2012; or Redshaw Point *sensu* Pirrie *et al.*, 1997a) and at Redonda Point (Lirio *et al.*, 1989; Fig. 1).

The Rabot Formation consists of interbedded mudstones, sandstones, tuffs and minor conglomerates representing the distal facies of a regressive sequence of a storm-dominated platform (Lirio *et al.*, 1989). The unit is approximately equivalent to the Beta Member of the Santa Marta Formation (Olivero *et al.*, 1986; Olivero, 2012), exposed at the northwest of James Ross Island (Figs. 1–2).

Based on the invertebrate fauna and palynomorphs (Lirio *et al.*, 1989; Palamarczuk *et al.*, 1990; Marenssi *et al.*, 1992; Palamarczuk, 1993; Pirrie *et al.*, 1997a; Olivero, 2012; Amenábar & Lirio, 2015), an early Campanian age was proposed for the Rabot Formation. Olivero (2012) included the Rabot Formation in the N sequence (Santonian–lower to basal upper Campanian). Milanese *et al.* (2017) suggested that the polarity transition in the middle levels of the Rabot Formation corresponds to C33r/C33n, with an age of 79.90 My according to Gradstein *et al.* (2012) and Gradstein *et al.* (2020) timescale (early Campanian) (Fig. 2).

MATERIAL AND METHODS

Specimens of the new dinoflagellate cyst species described in this work were recovered from 45 samples of mudstones and fine sandstones representing the Upper Cretaceous and Cenozoic units at Ekelöf Point and Rabot Point localities, southeast of James Ross Island.

Seven samples were collected at Ekelöf Point, which corresponds to the Hamilton Point Member of the Snow Hill Island Formation (Figs. 1–2). The samples were obtained from siltstones and claystones of a section of approximately 45 m thick and its palynological and micropaleontological assemblages were analyzed by Caramés *et al.* (2016). In the same locality, 20 samples from six scattered Cenozoic diamictites just above the Cretaceous deposits are also included in this analysis.

Then, 18 samples of the Rabot Formation were collected from members I, II, and III within an approximately 270 m thick outcrop at Rabot Point (Fig. 1). All the samples were collected from fine sandstones. The palynological analysis was carried out by Amenábar & Lirio (2015).

The palynological information from Hamilton Norte and Hamilton Point has been taken from the literature (Sumner, 1992; Pierre *et al.*, 1997a).

In the Laboratory of Palynology of the Universidad de Buenos Aires (UBA), Argentina, 18 Upper Cretaceous samples of the Rabot Formation and 20 samples of Cenozoic diamictites from Ekelöf Point were processed following the routine described by Wood *et al.* (1996), removing the organic matter by digestion of carbonates and silicates with HCl and HF, respectively. The residues were sifted through 25 μm and 10 μm sieve and mounted on microscope slides with glycerine jelly. All the Cretaceous samples from the Ekelöf Point were processed at the Technological Institute of Paleoceanography and Climatic Changes (itt OCEANEON) laboratory, Universidade do Vale do Rio dos Sinos (UNISINOS), Brazil. Samples were treated with HCl (32%) and HF (40%). The organic residue was sifted through a 10 μm sieve. Entellan was used as the mounting medium. In some cases, the inorganic fraction was removed by zinc chloride ($ZnCl_2$) with a gravity of 2.0.

The slides were examined at the Universidad de Buenos Aires using a Nikon 80i light microscope equipped with a Nikon Coolpix 900 digital camera and also at itt OCEANEON, using an Axioskop 40-Zeiss microscope and photographs were taken using Axion Vision software attached to the microscope. SEM photographs were taken at the Centro de Microscopía Avanzada (CMA) of the Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires.

Selected specimens are illustrated in Figures 3–5 and the palynological slides are denoted by the prefix BAFC-Pl, corresponding to the Palynological Collection of the Universidad de Buenos Aires, where the samples are stored.

A minimum of 200 palynomorphs, including dinoflagellate cysts, pollen, spores and others (*algae*, organic foraminiferal linings, scolecodonts, *fungi*, *etc.*) were counted in all samples. The taxonomic nomenclature of the dinoflagellate cysts is based on Fensome *et al.* (2019) and the suprageneric classification is based on Fensome *et al.* (1993). References to the dinoflagellate cyst taxa cited in this study can be found in Appendix 1.

SYSTEMATIC PALEONTOLOGY

Division DINOFLAGELLATA (Bütschli, 1885)
Fensome *et al.*, 1993
Class DINOPHYCEAE Pascher, 1914
Subclass PERIDINIPHYCIDAE Fensome *et al.*, 1993
Order GONYAULACALES Taylor, 1980
Suborder GONYAULACINEAE (autonym)
Family GONYAULACACEAE Lindemann, 1928
Subfamily LEPTODINIOIDEAE Fensome *et al.*, 1993

Genus ***Stiphrosphaeridium*** Davey, 1982 emend. nov.

Type species. *Stiphrosphaeridium dictyophorum* (Cookson & Eisenack, 1958) Lentin & Williams, 1985. Upper Mesozoic, Australia and New Guinea.

Remarks. Williams *et al.* (2017) indicated that, although the "type species" was not validly transferred by Davey (1982, p. 16, 35), the generic name *Stiphrosphaeridium* was validly published by that author since it is based on a previously validly published species name (International Code of Botanical Nomenclature, Article 40.3; Turland *et al.*, 2018).

Original diagnosis. "Shape: The body is spherical to subspherical in shape with only minor dorso-ventral flattening. Wall: The wall of the cyst is apparently two-layered, the two layers being closely appressed except where the periphragm alone forms the processes. The surface is smooth to scabrate. Paratabulation: Parasutures not observed. Processes: The plate-centered processes are solid and fenestrate. Paracingular processes are absent. The pre-, postcingular (2 – 6´´) and antapical processes are the largest but do vary in size depending on their position on the cyst. The processes may be solid for most of their length before becoming fenestrate, or the fenestration may extend down to the body surface. Distally these larger processes each terminate in a more or less complete circular trabeculum; in the smaller process (1 – 4´, 1ps, 1p) the trabeculae are sometimes incompletely developed. The process formula is 4´, 6´´, 6´´´, 1p, 1´´´´, 1ps, plus 0-4s. Archaeopyle: An apical archaeopyle is developed by the apical paraplates as a unit (Type Ā). The archaeopyle has a strongly zigzagged" (Davey, 1982, p. 16).

Emended diagnosis. The cyst can bear 17 to 23 intratabular processes, the genus has either one solid stem or several distally coalescing stems to form a single process, giving some of the processes a fibrous appearance.

Process can be solid proximally and some become hollow funnel-shaped, may have fenestrate distal expansions, develop complete or incomplete circular distal trabecula, or end up in a trumpet shape with a smooth and continuous edge or finely serrated margins.

Discussion. Stover & Williams (1987, p. 203–204) summarized the major morphological characters of the genus *Stiphrosphaeridium* providing the following synopsis: "Cyst skolochorate, body subspherical and bears 17 to 23 intratabular processes with generally solid stems and hollow funnel-shaped, fenestrate distal expansions; cingular processes absent; adjacent processes not connected by trabeculae; paratabulation indicated by type [4A] apical archaeopyle and by processes; formula: 4´, 6´´, 0c, 5 – 6´´´, 1p, 1´´´´ and 1 – 5s; operculum free". They also modified the genus description as follows: "Wall relationships: Autophragm only or with endophragm and periphragm; when two-layered, walls are appressed except where periphragm form processes. Wall Features: Intratabular processes are funnel-shaped with generally solid stems and hollow, fenestrate, expanded distal ends; adjacent processes not connected by trabeculae. Cyst body smooth to scabrate. Archeopyle: Apical, type [4A], principal archeopyle suture zigzag; operculum free. Paratabulation: Indicated by archeopyle and intratabular processes; formula 4´, 6´´, 0c, 5 – 6´´´, 1p, 1´´´´ and 1 – 5s. Paracingulum: Indicated by absence of processes. Parasulcal indicated anteriorly by the sulcal notch and posteriorly by the posterior sulcal process; up to four additional sulcal processes may be present. Size: Intermediate to large, overall size about 60 μm to 130 μm".

Although Stover & Williams (1987) modified the original description of the genus *Stiphrosphaeridium*, they did not mention the presence of fibrous processes. Fauconnier & Masure (2004, p. 513–514) included some morphological features ("description") of *Stiphrosphaeridium* and listed the species attributed to the genus. In the case of *S. anthophorum*, they showed the fibrous-fenestrate nature of a process in a schematic draw (Fauconnier & Masure, 2004, pl. 77, fig. 2), although such characteristic was not included in their description. In agreement with what Fauconnier &

Masure (2004) showed in their schematic draw, we emphasize the fibrous appearance of the processes in *S. anthophorum*. Thus, the diagnosis of the genus should include both solid and fibrous stem processes.

Comparisons. The specimens studied here are assigned to the genus *Stiphrosphaeridium* instead of *Systematophora*,

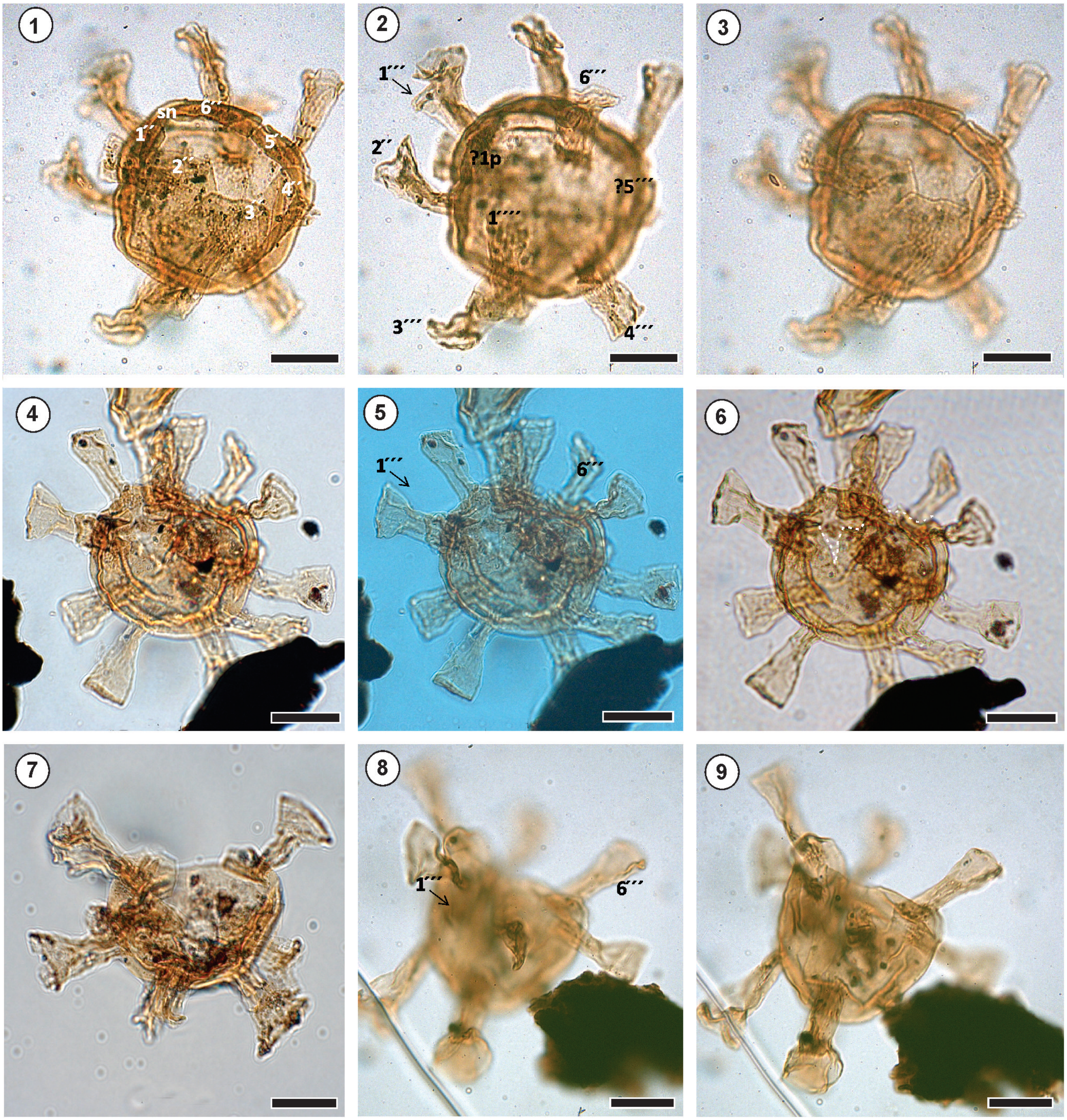

Figure 3. 1–9, ***Stiphrosphaeridium sobralii*** sp. nov. from the Upper Cretaceous of the Hamilton Point Member of the Snow Hill Island Formation at Ekelöf Point (1–7) and the member III of the Rabot Formation at Rabot Point (8–9), southeastern James Ross Island, Antarctic Peninsula. England Finder references and microscopy coordinates are given for each specimen after the sample number. **1–3,** Holotype **BAFC-Pl 2446**: V49/4, apical-lateral view in different focus. Note the granular periphragm, probable due to a preservational feature. Parasulcal indicated anteriorly by the sulcal notch (**sn**); **4–6,** Paratype I **BAFC-Pl 2867**: R27/3, lateral views in different focus, normal light microscopy; **5,** Enhancement of the specimen outline by a blue light filter; **6,** Note the apical archaeopyle with a zig-zag margin (indicated by the white dotted line) and the distribution of processes; **7,** Paratype II **BAFC-Pl 2867**: V23/2, lateral view; **8–9,** Paratype III **BAFC-Pl 2443**: X50/4, the same specimen in different focus. Note the absence of paracingular processes. Scale bar= 20 μm.

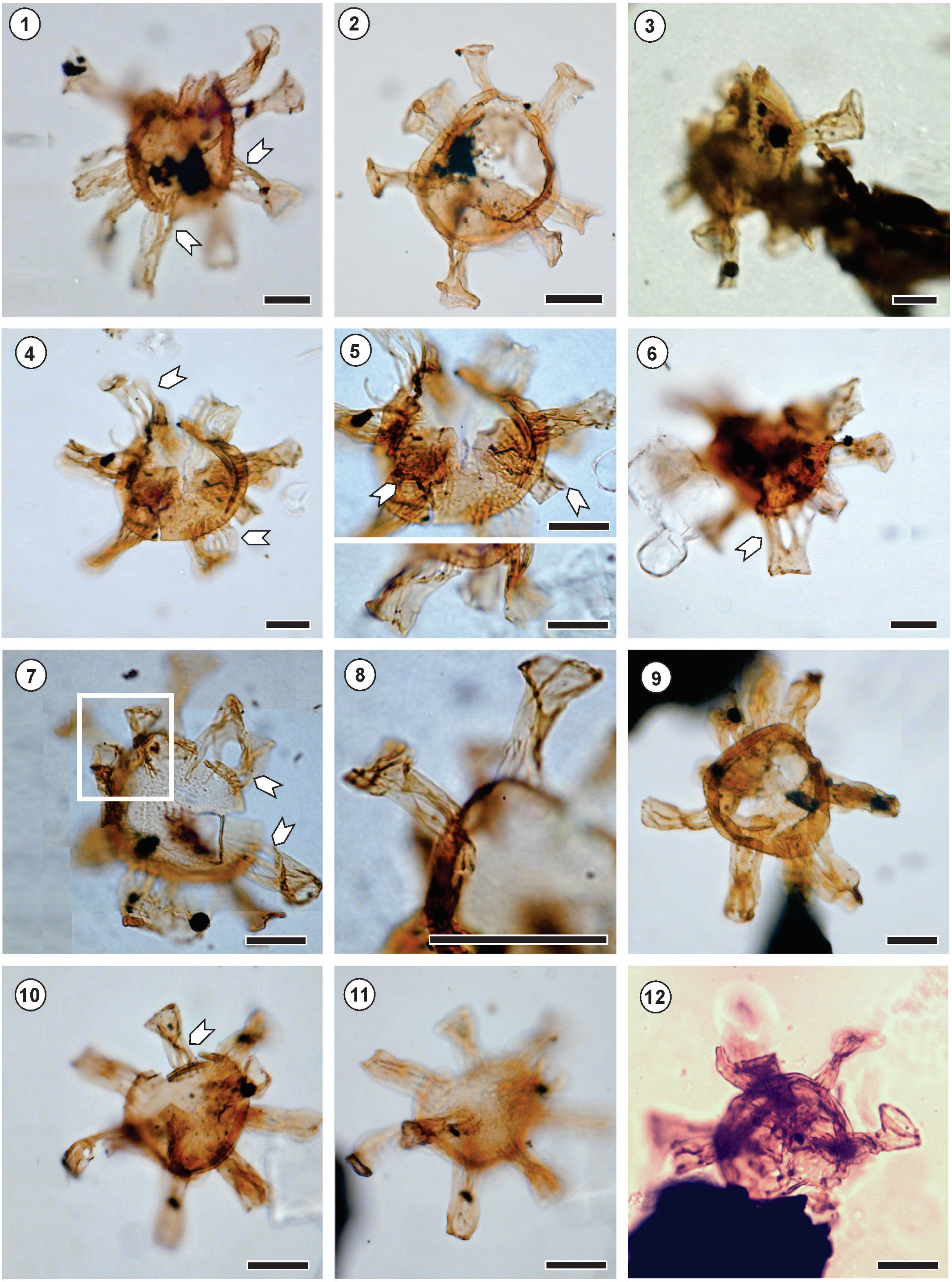
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Figure 4. ***Stiphrosphaeridium sobralii*** sp. nov. **1–11,** from the Upper Cretaceous of member III of the Rabot Formation at Rabot Point and **12,** the Hobbs Glacier Formation at Ekelöf Point, southeastern James Ross Island, Antarctic Peninsula. England Finder references are given for each specimen after the specimen number. **1, BAFC-Pl 2497**: X26, note the fibrous appearance in the base of the processes; **2–3,** note the hollow funnel-shaped termination of the processes, **2, BAFC-Pl 2540**: Z25; **3, BAFC-Pl 2540**: F26; **4–5, BAFC-Pl 2497**: B20 in apical-lateral views; **4,** note the fibrous appearance in the base of the processes indicated by white arrows; **5,** detail of the specimen showing the apical archaeopyle with zig-zag margin and the precingular processes (indicate by white arrows). Note the finely granulate periphragm probably due to a preservational feature; **6, BAFC-Pl 2497**: A35, note the fibrous appearance in the base of the processes shown by white arrows; **7–8, BAFC-Pl 2497**: C35, note the fibrous appearance in the base of the processes shown by white arrows, and the finely granulate periphragm; **8,** detail of the specimen, the area enclosed in a white square shows the folds in the terminations and the flat appearance of the processes; **9, BAFC-Pl 2467**: J45, apical view of the archaeopyle; **10–11, BAFC-Pl 2467**: P51 in apical-lateral view, note the archaeopyle and the fibrous process (indicate by a white arrow); **12, BAFC-Pl 2362-2**: Z56/4, reworked specimen, diamictite D6-9. Scale bar= 20 µm.

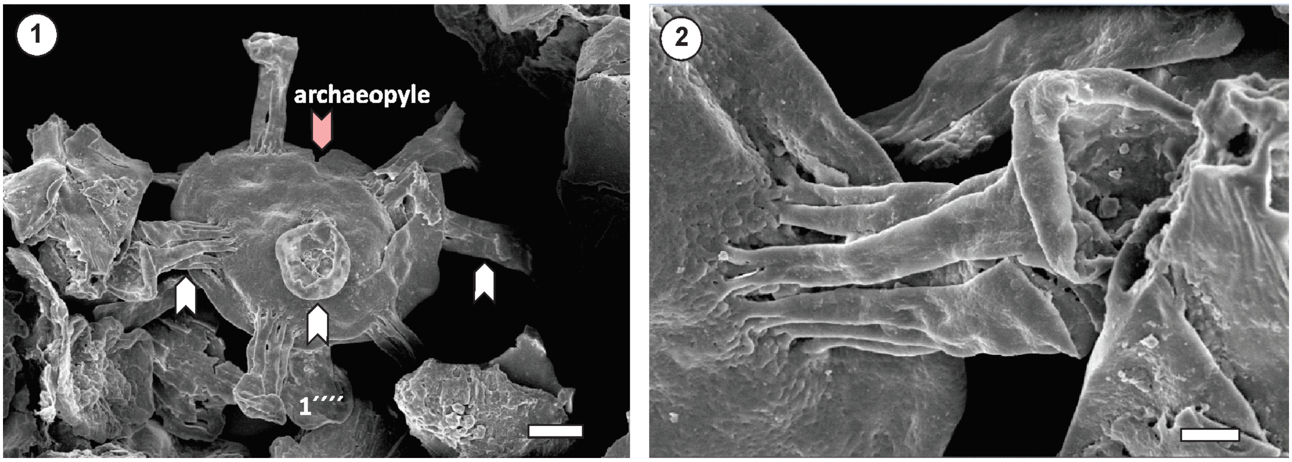

Figure 5. Scanning electron microscope (SEM) images of ***Stiphrosphaeridium sobralii*** sp. nov. **BAFC-Pl 2867**, from the Upper Cretaceous of the Hamilton Point Member of the Snow Hill Island Formation at Ekelöf Point, southeastern James Ross Island, Antarctic Peninsula. **1,** Lateral antapical view. Note the antapical and postcingular processes (indicate by white arrows) and the archaeopyle margin. Scale bar= 20 µm; **2,** Detail of the processes. Note the fibrous nature of the base of the process. Scale bar= 3 µm.

Oligosphaeridium, *Hystrichosphaeridium*, and *Rigaudella* because of the following differences: *Systematophora* (Klement) emend. Brenner (1988) Stancliffe & Sarjeant, 1990, has one penitabular complex of process per paraplate and has paracingular processes. Riding & Helby (2001) modified the original diagnosis of Brenner (1988) to include the presence of two paired process groups in each of the plates in the paracingular series, instead of each paraplate in the apical series bearing an essentially complete process group. Whichever emendation is considered, *Stiphrosphaeridium* has only one centrally located process per plate.

Oligosphaeridium Davey & Williams (in Davey *et al.*, 1966) emend. Davey, 1982 has processes with a similar distribution to the specimens analyzed here, but the genus does not include fibrous processes and they are mostly hollow and always tubiform (except for a solid process present in a 1´´´ position and one that may be present in a parasulcal region, after the emendation of the genus *Oligosphaeridium* proposed by Davey, 1982, p. 13).

Hystrichosphaeridium (Deflandre) emend. Davey & Williams, 1966 has intratabular hollow processes but also has paracingular processes.

Rigaudella Below, 1982 also has funnel-shaped intratabular processes and lacks a paracingular process but differs from *Stiphrosphaeridium* in having distally expanded processes connected to each other by trabeculae.

Stiphrosphaeridium sobralii sp. nov.

Figures 3–7

LSID urn:lsid:plantfossilnames.org:act:3305

1992 *Oligosphaeridium* sp. A Sumner, fig. 3f, i.
1997a *Oligosphaeridium* sp. A Sumner, 1992. Pirrie *et al.*, fig. 6 (f).
2016 *Oligosphaeridium* sp. A Sumner, 1992. Caramés *et al.*, listed in tab. 2.

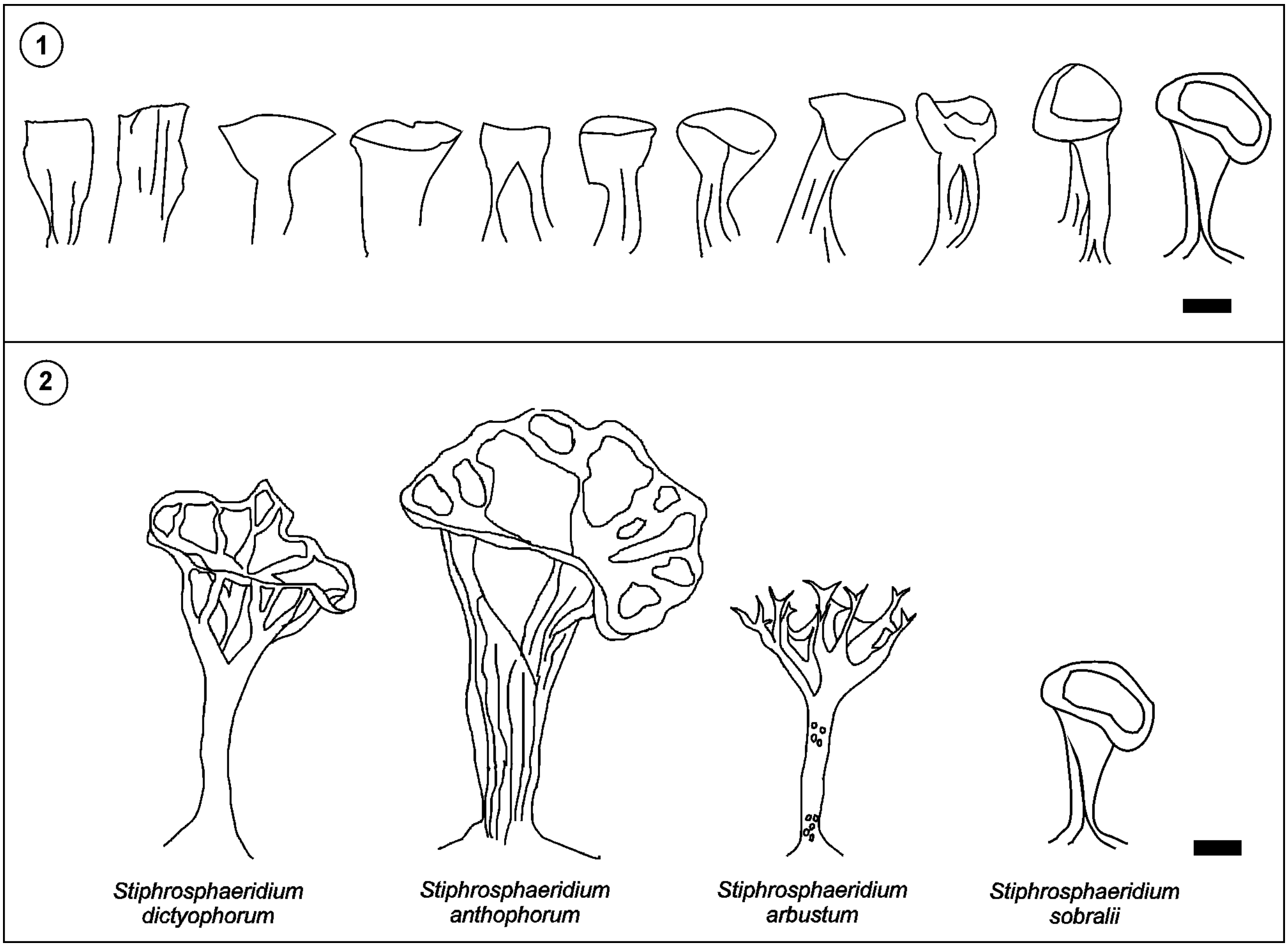

Figure 6. 1, Drawings showing different processes of ***Stiphrosphaeridium sobralii*** sp. nov.; **2,** Redrawn from Fauconnier & Masure (2004), showing the processes of different species of ***Stiphrosphaeridium***. The most characteristic process of ***Stiphrosphaeridium sobralii*** is shown for comparison. Note the typical trumpet-like ends and the smaller size of the process compared to other species. Scale bar= 5 µm.

Derivation of name. In honour of José María Sobral, a patriotic naval officer and the first Argentine geologist who carried out research work in Antarctica during the forced overwintering at Cerro Nevado (=Snow Hill) Island in 1902. He was a member of the Swedish Antarctic Expedition (1901–1903) headed by Otto Nordenskjöld. Argentina's scientific research on the Antarctic continent began with Sobral.

Diagnosis. Processes deeply fibrous at their bases, expanding at the distal end like a trumpet, with open extremities and smooth distal margin, without fenestrated or reticulate distal terminations.

Type Material. Holotype, BAFC-Pl 2446: V49/4 (Fig. 3.1–3).

Referred Material. Paratype I, BAFC-Pl 2867: R27/3 (Fig. 3.4–6); Paratype II, BAFC-Pl 2867: V23/2 (Fig. 3.7); Paratype III, BAFC-Pl 2443: X50/4 (Fig. 3.8–9).

Description. Chorate cyst, having a spherical to subspherical body shape. The cyst wall (1.5–2 µm) comprises an endophragm and periphragm, which are closely appressed, except where the periphragm forms the processes. The periphragm, smooth to finely granulate, develops intratabular processes, one per paraplate. The processes arise from several proximal stems, which coalesce distally to form a single process, all of a similar length, giving the process a fibrous appearance. Tubiform processes broaden distally in a trumpet form. Processes widely expanded and open distally, with a smooth continuous edge. Processes usually show folds near the extremity and are flat-looking. The gonyaulacoid paratabulation (4´, 6´´, 0c, 6´´´, 1p, 1´´´´, 1ps, plus 0–4s) is reflected by the distribution of intratabular processes; paracingular and parasulcal processes are absent. The archaeopyle is apical, type (tĀ), with a zig-zag margin. The operculum is free (Figs. 3–7).

Dimensions. Total diameter: 56–100 µm. Diameter of body: 37–60 µm; length of processes: 18–28 µm; width of processes: 6.3–9.6 µm (proximally) and 11–17.3 µm (distally). Archaeopyle width: 30–38 µm. All measures based on eight specimens.

Holotype. Total diameter: 102 µm; diameter of body: 60 µm; length of processes: 22–28 µm; width of processes: 4.5–9 µm (proximally) and 11–15 µm (distally). Paratype I: total diameter: 91.5 µm; diameter of body: 49 µm; length of processes: 19–23.5 µm; width of processes: 6.3–9.4 µm (proximally) and 12.3–16.7 µm (distally). Paratype II: total diameter: 73.8 µm; diameter of body: 52.7 µm; length of processes: 20.6–21.1 µm; width of processes: 7.4–9.6 µm (proximally) and 17.2–17.3 µm (distally). Paratype III: total diameter: 77 µm; diameter of body: 37 µm; length of

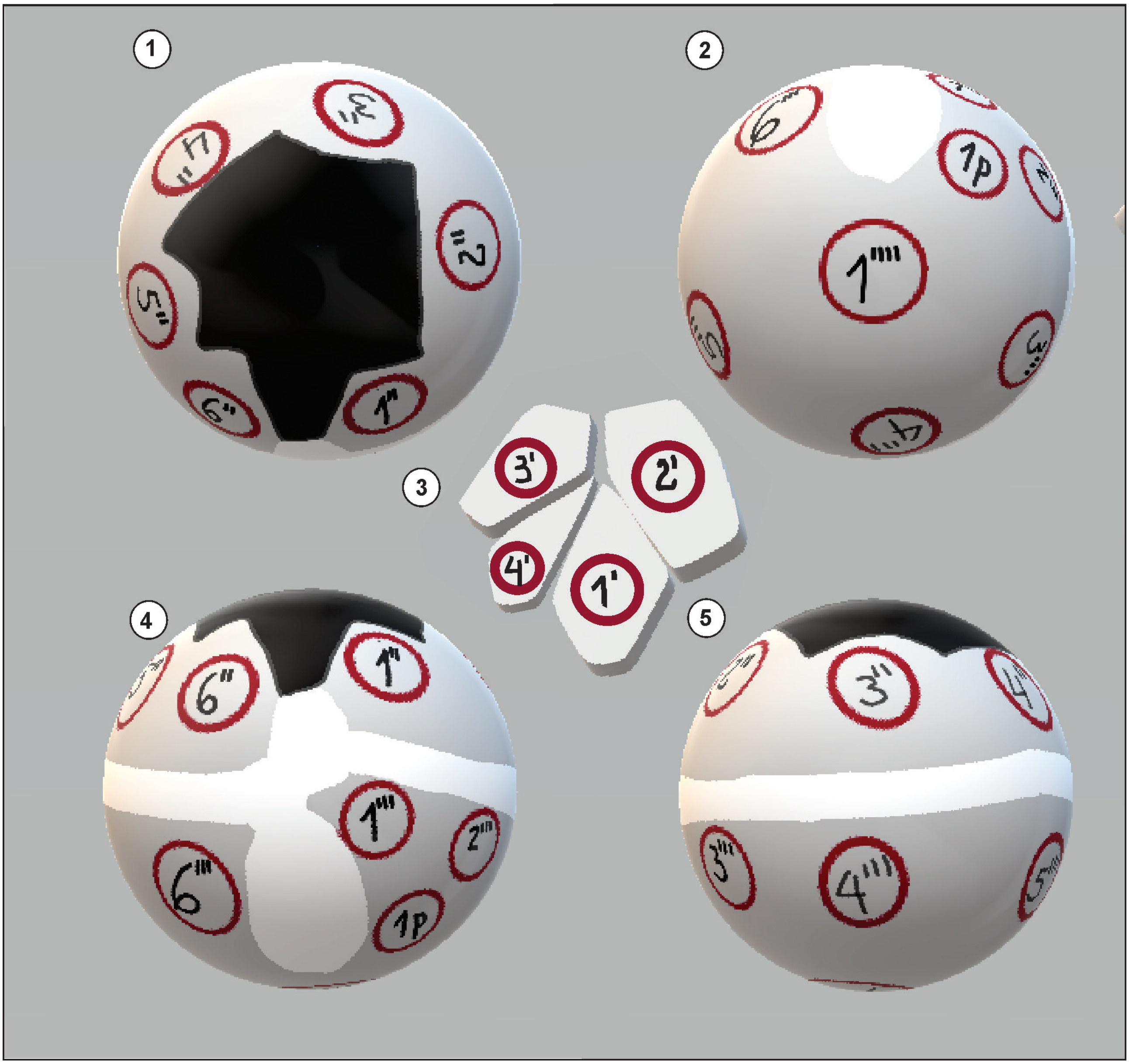

Figure 7. Schematic of the paratabulation of ***Stiphrosphaeridium sobralii*** sp. nov. inferred from the distribution of intratabular processes. **1,** Apical view; **2,** Antapical view; **3,** Archaeopyle; **4,** Ventral view; **5,** Dorsal view. The circles indicate the position of the processes. Paracingular and parasulcal processes are absent.

processes: 20–24 μm; width of processes: 5–6 μm (proximally) and 8–12 μm (distally).

Remarks. The gonyaulacoid paratabulation (4´, 6´´, 0c, 6´´´, 1p, 1´´´´, 1ps, plus 0–4s) proposed by Davey (1982) is difficult to see in the studied specimens because most of them are folded or compressed. The granular wall may be a primary effect but a preservational feature as a consequence of bad preservation is not ruled out. Paratabulation is inferred from the position of the processes and the angularity of the archeopyle (Fig. 7; Supplementary Information).

Geographic occurrence. Rabot Point and Ekelöf Point, Southeast James Ross Island, James Ross Basin, Antarctic Peninsula (this work). It was also recognized as *Oligosphaeridium* sp. A Sumner, 1992, at Hamilton Point and Hamilton Norte (=Redshaw Point, Pirrie *et al*., 1997a).

Stratigraphic occurrence. The middle Campanian (members I, II, III of the Rabot Formation) and upper Campanian (Hamilton Point Member of the Snow Hill Island Formation). In upper Pliocene diamictites of the Hobbs Glacier Formation or Gage Formation, *Stiphrosphaeridium sobralii* is interpreted as reworked taxa.

Comparisons. *Stiphrosphaeridium sobralii* differs from *Stiphrosphaeridium dictyophorum*, which has deeply fenestrated and branched processes in their distal ends, crowned by a more or less developed circular trabecula (as described by Fauconnier & Masure, 2004), while in the new species the processes are not connected by trabecula; moreover, their processes are shorter than in *Stiphrosphaeridium dictyophorum*, which are 42 to 37 μm long (Fig. 6).

Stiphrosphaeridium anthophorum has also striated processes composed of longitudinal fibrils that gradually widen distally into deep terminal expansions, but unlike *Stiphrosphaeridium sobralii*, the terminal expansions have completely and irregularly reticulate walls and continuous smooth or finely serrated outer edges. Besides, the processes are about 50 μm length (Cookson & Eisenack, 1958) (Fig. 6).

Stiphrosphaeridium arbustum has fenestrated processes, with incomplete trabecula and the processes are thinner and larger than *Stiphrosphaeridium sobralii* (Fig. 6).

DISCUSSION

Biostratigraphic considerations

Stiphrosphaeridium sobralii is recorded from two Antarctic stratigraphic units: The Campanian Rabot Formation and the Hamilton Point Member of the Snow Hill Island Formation (Fig. 8). In the Rabot Formation, it occurs in member III (approximately equivalent to unit c of Pirrie *et al*., 1997a) along with *Satyrodinium bengalense*, *Heterosphaeridium heteracanthum*, *Odontochitina cribopoda*, *O. porifera*, and *Trichodinium castanea* (Amenábar & Lirio, 2015). Based on the presence of *Satyrodinium bengalense*, Amenábar & Lirio (2015) correlated this Antarctic assemblage with two of the dinoflagellate zones of New Zealand proposed by Crampton *et al.* (2000): *Satyrodinium haumuriense* (lower to middle Campanian) and the lowest part of *Isabelidinium pellucidum* (upper Campanian), suggesting that the age of the member III would range from the early to middle Campanian and possibly extending into the late Campanian (in terms of the Campanian tripartite division).

Although the entire Upper Cretaceous succession of the Rabot Formation at Rabot Point was analyzed for the present study, *Stiphrosphaeridium sobralii* was only found in member III and not in members I and II. However, previous records of this species by Sumner (1992) (as *Oligosphaeridium* sp. A) indicate its occurrences in unit a and in the lower part of unit b (equivalent to member I and the lower part of member II). In those assemblages, *Stiphrosphaeridium sobralii* (as *Oligosphaeridium* sp. A) has been found together with ?*Heterosphaeridium heteracanthum*, *Isabelidinium* spp., *Nelsoniella aceras*, *N. semireticulata*, *N. tuberculata*, *Nelsoniella* spp., *Odontochitina costata*, *O. operculata*, *O. porifera*, *Oligosphaeridium pulcherrimum*, *Phelodinium exilicornutum*, *Prolixosphaeridium* sp., *Satyrodinium bengalense*, *Spiniferites ramosus*, and ?*Xenikoon australis* (Fig. 8). Other records of *Stiphrosphaeridium sobralii* (as *Oligosphaeridium* sp. A) were documented by Pirrie *et al.* (1997a) in the uppermost part of unit b and unit c (equivalent to the uppermost of the member II and the member III). They registered this species along with ?*Diconodinium* sp., *Nelsoniella aceras*, *N. tuberculata*, *Odontochitina porifera*, *Oligosphaeridium pulcherrimum*, *Satyrodinium bengalense*, *S. haumuriense*, *Spiniferites ramosus*, *Tanyosphaeridium xanthopyxides*, *Trichodinium castanea*, and

Xenikoon australis (Fig. 8). The authors suggested an early Campanian age for the Rabot Formation based on the presence of *Nelsoniella aceras*, *N. tuberculata*, *Satyrodinium bengalense*, and ?*Xenikoon australis.* Therefore, the palynological information suggests an early to middle Campanian age for the Rabot Formation, with the possibility of extending into the late Campanian; the magnetostratigraphic results (Milanese *et al.*, 2019, 2020) confirm a middle Campanian age for the unit (Fig. 8).

Stiphrosphaeridium sobralii was also found in the Hamilton Point Member of the Snow Hill Island Formation at Ekelöf Point and Hamilton Point (Pirrie *et al.*, 1997a). At Ekelöf Point, Caramés *et al.* (2016) recovered the new species (as *Oligosphaeridium* sp. A) together with *Isabelidinium cretaceum*, *I. papillum*, *I. pellucidum*, *Phelodinium magnificum*, *Tanyosphaeridium xanthiopyxides*, *Amphidiadema denticulata*, *Laciniadinium* ?*biconiculum*, and *Manumiella* sp. cf. *M. seymourensis* (Fig. 8). They suggested a late Campanian age for the Hamilton Point Member, based on the common co-occurrence of *Isabelidinium pellucidum* and *Isabelidinium cretaceum*, along with *Odontochitina* spp. and *Tanyosphaeridium xanthiopyxides.* However, an earliest Maastrichtian could not be dismissed because of the presence of *Manumiella* sp. cf. *M. seymourensis* in the assemblage. Later, Milanese *et al.* (2020) identified the Magnetochron C32/C33 boundary at the upper part of the Hamilton Point Member (Fig. 2). Based on this information, the age of the Hamilton Point Member of the Snow Hill Island Formation cannot be younger than the late Campanian. Thus, the age of their palynological assemblages and the biostratigraphic range of *Stiphrosphaeridium sobralii* can be restricted to the middle to late Campanian.

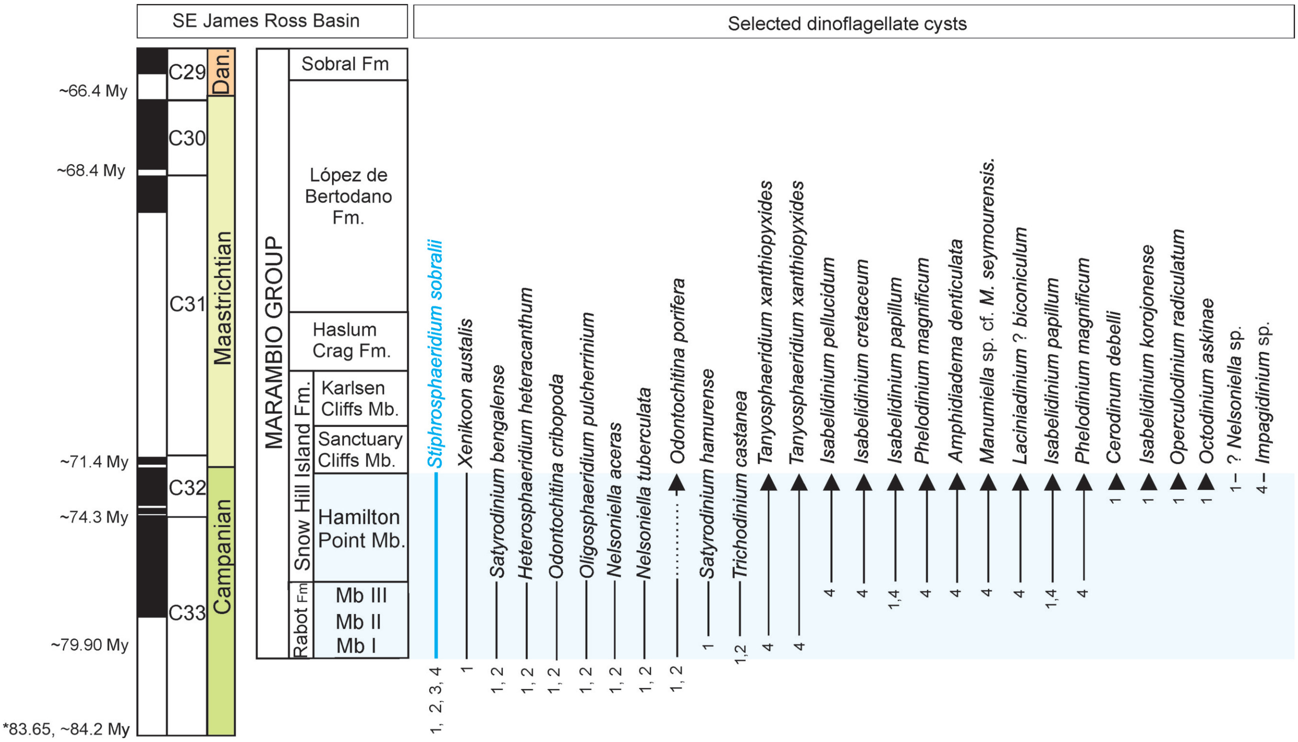

Figure 8. Stratigraphical occurrence of ***Stiphrosphaeridium sobralii*** sp. nov. and selected associated dinoflagellate cyst species in the Antarctic units. Note that the species ranges continue in the upper units although they are not shown in the figure. Chronostratigraphy for the Marambio Group after Milanese *et al.* (2020) and polarity time scale from Ogg *et al.* (2016). The age of ~79.90 and ~84.2 My are taken from Milanese *et al.* (2017) and their positions in this figure are tentative. *Updated age (83.65 My) according to Gradstein *et al.* (2020). The light blue box indicates the range of the new species. Doubtful records are indicated by a question mark (?) and a dashed line indicates no records. Biostratigraphic range references: **1,** Rabot Formation at Rabot Point, Hamilton Norte (=Redshaw Point) (Pirrie *et al.*, 1997a). Hamilton Point Member of the Sanctuary Cliffs Formation at Ekelöf Point and Hamilton Point (Pirrie *et al.*, 1997a); **2,** Rabot Formation at Rabot Point (Amenábar & Lirio, 2015); **3,** Hamilton Point Member of Santa Marta Formation (*sensu* Pirrie *et al.*, 1997a) at Ekelöf Point (Sumner, 1992); **4,** Hamilton Point Member at Ekelöf Point (Caramés *et al.*, 2016).

Stiphrosphaeridium is a cosmopolitan genus with a worldwide distribution spanning the Late Jurassic (early Kimmeridgian) and Early Cretaceous (Aptian, probably into the Albian) (Stover & Williams, 1987; Fauconier & Masure, 2004). In Antarctica, the first record of the genus corresponded to *Stiphrosphaeridium anthophorum* from the lower Maastrichtian Cape Lamb Member of the Snow Hill Island Formation, northeast of James Ross Island (Figs. 1–2). In this locality, although 46 specimens were reported, only one was illustrated (Guerrero-Murcia *et al*., 2023, fig. 5.15), in which deeply fenestrated processes are easily visible, a feature that distinguishes it from *Stiphrosphaeridium sobralii* (Fig. 6). The new species described here corresponds to the second record of the genus in the James Ross Basin, Antarctic Peninsula, showing that the genus ranges in age from the Campanian to the early Maastrichtian.

Specimens of *Stiphrosphaeridium sobralii* from the Antarctic Cenozoic diamictites at Ekelöf Point (Adamonis *et al*., 2010) are registered together with large amounts (approximately 80% of the total of the assemblage) of Late Cretaceous reworked species (*e.g.*, *Isabelidinium* spp., *Odontochitina porifera*), probably from the underlying Snow Hill Island Formation, and also with rare Cenozoic taxa (*e.g.*, *Spiniferites ramosus*, *Lejeunecysta* sp.). To date, no specimens that would be assignable to *Stiphrosphaeridium sobralii* have been recorded from Maastrichtian–Paleogene Antarctic strata. Therefore, two possible options could be considered: 1. that the new species has a sporadic record, appearing in the Campanian and reappearing in the upper Pliocene; or 2. that *Stiphrosphaeridium sobralii* is a Campanian species reworked in Neogene deposits. The latter is the most likely option, as recycling is a common process in Antarctic Neogene diamictites (*e.g.*, Salzmann *et al*., 2011).

Paleoenvironmental affinities

Stiphrosphaeridium sobralii was previously recorded as *Oligosphaeridium* sp. A from distal facies of the southeast of the James Ross Basin (Ekelöf Point, Rabot Point, Hamilton Norte and Hamilton Point). Olivero (2012) characterized these deposits as representing mid- to outer-shelf environments for the Rabot Formation and outer-shelf environments for the Hamilton Point Member of the Snow Hill Island Formation. Likewise, Raffi *et al.* (2019) found that gaudryceratid ammonites were extremely abundant and diverse in the Rabot Formation, suggesting an offshore oceanic-influenced environment during the Campanian in the southeast area of the James Ross Basin.

The Hamilton Point Member of the Snow Hill Island Formation yielded an ostracod fauna indicative of a shelf environment (Fauth *et al*., 2003). Similarly, based on foraminiferal morphogroups and sedimentological data, Caramés *et al.* (2016) proposed an outer shelf-upper bathyal environment for the unit. Furthermore, the latter authors suggested that the abundance of terrestrial palynomorphs together with the dominance of peridinioid (which are more abundant in highly productive environments) over gonyaulacoid dinoflagellate cyst taxa, could be due to the existence of a narrow continental shelf, where terrestrial palynomorphs and peridinioid cysts were rapidly transported down the slope and deposited in a deeper marine environment, where they mixed with gonyaulacoid cysts of outer neritic to oceanic environments (*e.g.*, *Impagidinium*). The upwelling processes that bring large amounts of dissolved nutrients to the surface waters (Sluijs *et al*., 2005) could be another explanation for the abundance of peridinioid cysts in the outer neritic or oceanic environments, together with *Impagidinium* and other offshore environment taxa.

CONCLUSIONS

Stiphrosphaeridium sobralii sp. nov. is a gonyaulacalean dinoflagellate cyst recognized for its characteristic fibrous processes that are expanded in the distal extreme like a trumpet, within Upper Cretaceous Antarctic palynological assemblages. It is recorded throughout the middle to upper Campanian in the southeast area of the James Ross island. The new species may therefore prove to be a significant biostratigraphic marker for this interval. Up to now, it has only been recorded in distal facies that typically occur in the southeast area of the James Ross Island. The foraminiferal faunas and gaudryceratid ammonites registered in these deposits, indicative of outer shelf marine settings, suggest that *Stiphrosphaeridium sobralii* was common in offshore environments.

Up to date, the new species has only been recorded in the Antarctic Peninsula area, precluding regional correlation with other Gondwanan sites, *i.e.*, Australia and New Zealand.

However, the identification of new species with restricted and well-defined biostratigraphic ranges, as the case of *Stiphrosphaeridium sobralii*, with ranges calibrated with magnetostratigraphy, will allow the establishment of a high-resolution framework for the Upper Cretaceous of the James Ross Basin.

ACKNOWLEDGMENTS

We thank the Dirección Nacional del Antártico (DNA)-Instituto Antártico Argentino (IAA) and the Fueza Aérea Argentina for their logistical support during the Argentine Summer Antarctic Expedition 2008 and 2009. This work was carried out as part of the Micropaleontology project within the Argentine Antarctic Program. We thank A. Concheyro, J. M. Lirio, S. Adamonis, A. Mackern and M. Ercoli for their help with sampling and geological observations. We are grateful to the Technological Institute of Paleoceanography and Climatic Change (itt OCEANEON), Universidade do Vale do Rio dos Sinos (UNISINOS) Brazil, and M. Barbé (Universidad de Buenos Aires) for the preparation of palynological samples. To the Centro de Microscopía Avanzada (CMA) of the Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires for the SEM photographs. Thanks to F. Milanese for the discussion of the magnetostratigraphic results of the studied lithostratigraphic units, to A. Prieto as Editor and two anonymous reviewers, whose comments improved the manuscript. G. R. Guerstein acknowledge to the Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET). This paper is the contribution number R-475 of the Instituto de Estudios Andinos 'Don Pablo Groeber' (IDEAN-CONICET). It is also a contribution to the project "Evolução climática do Paleoceno–Mioceno: Conexões entre o Oceano Austral e a Península Antártica" and the project "Evolução paleoambiental e paleoclimática da Península Antártica: Correlação entre as margens oriental e ocidental com base na paleoflora", both from Programa Antártico Brasileiro - PROANTAR - CNPq, MCTIC, CAPES, FNDCT.

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Editorial Note: Both this work and the nomenclatural acts it contains have been registered in the Plant Fossil Names. The work is permanently archived in the Internet Archive.
Plant Fossil Names Registry Number: PFN003305.

doi: 10.5710/PEAPA.15.02.2024.487

Recibido: 27 de septiembre 2023
Aceptado: 15 de febrero 2024
Publicado: 12 de junio 2024

APPENDIX 1

List of dinoflagellate cyst species cited in this work with authorships (after Fensome *et al.*, 2019)

Amphidiadema denticulata Cookson & Eisenack, 1960
?*Heterosphaeridium heteracanthum* (Deflandre & Cookson, 1955) Eisenack & Kjellström, 1972 emend. Radmacher *et al.*, 2014
Isabelidinium cretaceum (Cookson, 1956) Lentin & Williams, 1977
Isabelidinium papillum Sumner, 1992
Isabelidinium pellucidum (Deflandre & Cookson, 1955) Lentin & Williams, 1977
Laciniadinium ?biconiculum McIntyre, 1975
Manumiella sp. cf. *M. seymourensis* Askin, 1999
Nelsoniella aceras Cookson & Eisenack, 1960
Nelsoniella semireticulata Cookson & Eisenack, 1960
Nelsoniella tuberculata Cookson & Eisenack, 1960
Odontochitina costata (Alberti, 1961) emend. Clarke & Verdier, 1967
Odontochitina cribropoda Deflandre & Cookson, 1955
Odontochitina operculata (Wetzel, 1933) Deflandre & Cookson, 1955
Odontochitina porifera Cookson, 1956
Oligosphaeridium pulcherrimum (Deflandre & Cookson, 1955) Davey & Williams, 1966
Phelodinium exilicornutum Smith, 1992
Satyrodinium haumuriense (Wilson, 1984) Lentin & Manum, 1986
Satyrodinium bengalense Lentin & Manum, 1986
Spiniferites ramosus (Ehrenberg, 1837) Mantell, 1854
Stiphrosphaeridium anthophorum (Cookson & Eisenack, 1958) Davey, 1982
Stiphrosphaeridium dictyophorum (Cookson & Eisenack, 1958) Lentin & Williams, 1985
Stiphrosphaeridium arbustum Davey, 1982
Tanyosphaeridium xanthiopyxides (Wetzel, 1933 ex Deflandre, 1937) Stover & Evitt, 1978
Trichodinium castanea Deflandre, 1935 ex Clarke & Verdier, 1967
Xenikoon australis Cookson & Eisenack, 1960