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# Palaeogene Charophytes of the Balearic Islands (Spain)

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## ABSTRACT

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Fossil charophytes were recorded in two different stratigraphic units from the non-marine Palaeogene of the Balearic Islands. In the Peguera Limestone Fm. of Mallorca the charophyte flora is characterised by two assemblages. The first contains *Raskyella peckii* subsp. *meridionale*, *Harrisichara caeciliana* and *Maedleriella mangeloti*, from the Bartonian and Lutetian; whilst the second is characterised by *Harrisichara vasiformis-tuberculata* and *Nitellopsis (Tectochara) aemula*, Middle Priabonian in age. The Cala Blanca Detrital Fm. has yielded *Lychnothamnus stockmansii* and *Sphaerochara inconspicua* in Menorca whilst in Mallorca it contains *Lychnothamnus praelangeri*, *L. langeri* and *Sphaerochara hirmeri*. This flora is Late Priabonian and Oligocene in age. These results suggest that the beginning of Paleogene non-marine deposition was diachronic in Mallorca. In terms of biogeography, the Eocene charophytes of Mallorca show affinity with North-African floras. The presence of the Eocene African subspecies *Raskyella peckii meridionale* in Mallorca enables the biogeographic boundary between this form and the European subspecies *R. peckii peckii* to be drawn at about 32° N latitude in the Iberian Plate.

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**KEYWORDS** | Characeae. Biostratigraphy. Biogeography. Mallorca. Menorca. Palaeogene.

## INTRODUCTION

The Palaeogene record of the Balearic islands is limited to Mallorca, Menorca and Cabrera. However, non-marine Palaeogene rocks only crop out and show well-preserved charophyte flora in Mallorca and Menorca (Fig. 1A). This study provides an updated taxonomic, stratigraphic and biostratigraphic framework for these charophytes. The data obtained help correlate biostratigraphically the marine and lacustrine formations of the Balearic Islands and to compare biogeographically the charophyte floras of Europe and northern Africa.

Fossil charophytes were first reported from Mallorca by Hermite (1879), who found charophyte thalli ("tiges de *Chara*") in layers at Sta. Margarida, near Muro, which he attributed to the Late Eocene and which are now considered Early Miocene in age. Later on, the biostratigraphic pertinence of charophytes to the search for Balearic coal enhanced their study. In the mid-20<sup>th</sup> century, Guillem Colom found rich charophyte floras in the Palaeogene formations of Mallorca, which were determined by L. Grambast (Montpellier). Colom (1983), in a summary of his results, distinguished three lacustrine, charophyte-bearing units. The lower unit, characterised by

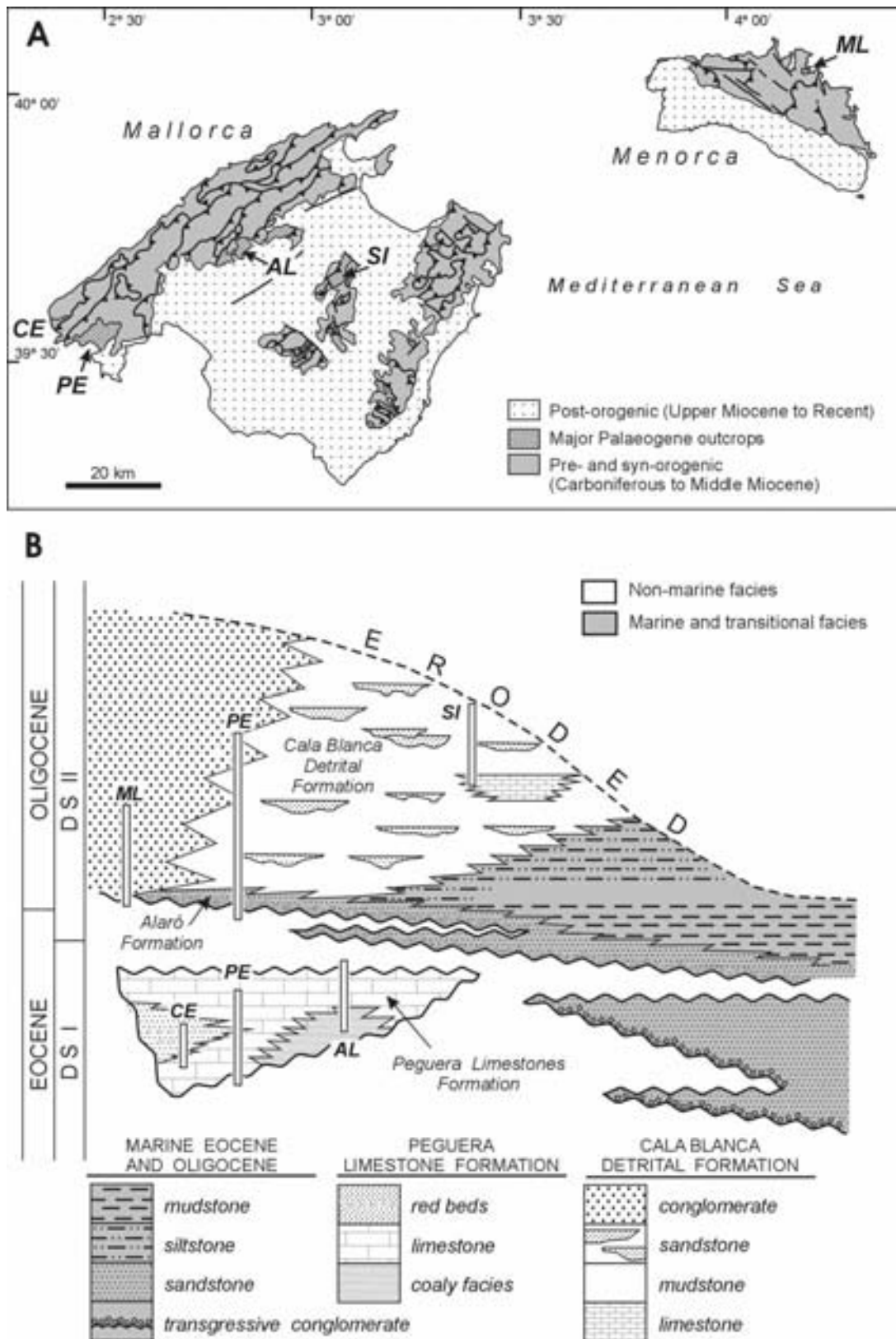


FIGURE 1 | Geological setting of the Palaeogene of the Balearic Islands. A) Schematic geological map of Mallorca and Menorca including the localities studied. B) Stratigraphic framework of the Palaeogene of the Balearic Islands and stratigraphic position of localities. Modified from Ramos et al. (2001).

Legend of localities: Sta. Ponça-Peguera and Cala Blanca outcrops (see Figs. 2 and 3); CE: Cala d'Egos (see Fig. 4); AL: Alaró and SI: Sineu (see Fig. 5); ML: Es Macar de sa Llosa (see Fig. 6).

*Tectochara meriani*, *Harrisichara tuberculata* and *Rhabdochara major*, was related to the Upper Eocene and Lower Oligocene (Ludian-Sannoisian). A second lacustrine interval was attributed to the Upper Rupelian (=Upper Stampian). This was based on the occurrence of *Tectochara meriani* var. *globula*, *T. cf. minutissima* and *Harrisichara cf. bressoni*. The upper lacustrine unit was attributed to the Burdigalian and contained *Rhabdochara langeri*. A new species, *Chara maioricensis* COLOM, 1967, was defined in this unit. The taxonomy and updated biostratigraphic attribution of the Palaeogene assemblages are discussed below. Charophytes of Menorca were first reported by Bourouilh (1973) from the Oligocene of Es Macar de sa Llosa and determined by Karl Mädler (Hannover) as *Tectochara meriani*, *Maedlisphaera ulmensis* and *Charites inconspicua*.

Understanding of the Palaeogene geology of Mallorca increased significantly between 1980 and 1990 (Anglada, 1985; Parés, 1985; Sàbat, 1986; Ramos-Guerrero, 1988). A synthesis of the Cenozoic tectosedimentary evolution of the island of Mallorca was proposed by Ramos-Guerrero et al. (1989), who supplied a first correlation between marine and continental deposits based on larger foraminifera and charophytes. These authors provided a preliminary list and a first dating of Palaeogene charophytes but the charophyte flora has not been studied till now.

The charophytes reported in the present study were collected in the non-marine Palaeogene outcrops of Mallorca and Menorca and from borehole cores (well S.1). Samples were washed and sieved through sieves of 1.0, 0.5 and 0.2 mm in lux. Gyrogonites were picked up under the light microscope and measured at 40x magnification. This material is housed in the Departament d'Estratigrafia, Paleontologia i Geociències marines, Universitat de Barcelona. A second set of samples include those collected by G. Colom from borehole samples (wells 13.1 and 9.1) supplied by coal mining companies in Mallorca, and sent to L. Grambast between 1950-1960. These samples are housed at the Laboratoire de Paléobotanique (Montpellier), which made them available for study. In summary, the following taxa from the Balearic Palaeogene are reported and described here:

#### Family Characeae

##### Genus *Maedleriella*

*Maedleriella mangenoti* GRAMBAST, 1957

*Maedleriella serialis* FEIST in Anadón et Feist, 1981

##### Genus *Harrisichara*

*Harrisichara caeciliana* SOULIÉ-MÄRSCHÉ, 1974

*Harrisichara vasiformis-tuberculata* FEIST-CASTEL, 1977

##### Genus *Nitellopsis*

*Nitellopsis (Tectochara) aemula* (GRAMBAST, 1972) GRAMBAST et SOULIÉ-MÄRSCHÉ, 1972

*Nitellopsis* sp.

##### Genus *Gyrogonia*

*Gyrogonia* sp. 1

*Gyrogonia* sp. 2

##### Genus *Lychnothamnus*

*Lychnothamnus praelangeri* (CASTEL, 1967) SOULIÉ-MÄRSCHÉ, 1989

*Lychnothamnus langeri* (ETTINGSHAUSEN, 1872) SOULIÉ-MÄRSCHÉ, 1989

*Lychnothamnus stockmansii* (GRAMBAST, 1957) SOULIÉ-MÄRSCHÉ, 1989

##### Genus *Sphaerochara*

*Sphaerochara hirmeri* (RASKY, 1945) MÄDLER, 1952

*Sphaerochara inconspicua* (UNGER, 1850) FEIST-CASTEL, 1977

*Sphaerochara* sp.

#### Family Raskyellaceae

##### Genus *Raskyella*

*Raskyella peckii* subsp. *meridionale* GRAMBAST, 1960

## STRATIGRAPHIC SETTING

The Palaeogene sedimentary record of the Balearic islands (Fig. 1B) has been divided into two depositional sequences, DS I and DS II, bounded by regional unconformities (Fornós et al., 2002). The lower sequence (DS I) records deposition in two palaeogeographic domains. In Cabrera and the S and SE of Mallorca the sequence is made up of marine deposits, whereas to the N and NW of Mallorca, the sequence is made up of non-marine rocks which constitute the Peguera Limestones Fm. According to dating of marine deposits, this sequence is Late Lutetian to Priabonian in age (Ramos-Guerrero et al., 1989). The upper sequence (DS II) includes marine and non-marine deposits forming a transgressive-regressive cycle. The marine transgressive deposits include the Alaró Fm (Fornós et al., 2002), whereas the overlying nonmarine deposits constitute the Cala Blanca Detrital Fm, which crops out in Mallorca and on the north side of Menorca. According to dating of marine rocks, this depositional sequence is Late Eocene (Priabonian) to Late Oligocene (Chattian) in age (Ramos-Guerrero et al., 1989).

This study focuses on the non-marine deposits that make up the Peguera and Cala Blanca Fms (Fig. 1B). The Peguera Fm is a succession, more than 140 m thick, of inner and marginal lacustrine carbonates (Ramos et al., 2001). The deeper and inner deposits are rich in organic matter, including coal beds. The shallow and marginal deposits are palustrine limestone, which locally shows

brecciation and root traces. The Peguera Fm records carbonate sedimentation in a freshwater lacustrine basin developed under warm and humid climatic conditions (Ramos et al., 2001). Previous data on the age of this formation were supplied by the mammal fauna found in Selva and neighbouring localities. They indicated a "Ludian" age (De Bruijn et al., 1978; Huguency and Adrover, 1982), which is considered equivalent to the Priabonian. The youngest age of the formation was also constricted by the overlying marine rocks of the Alaró Fm, which contain *Peneroplis evolutus*, *Austrotrillina howhini* and *Praerhapydionina delicata*, Late Priabonian to basal Rupelian in age (Ramos-Guerrero et al., 1989).

The Cala Blanca Detrital Fm is a succession, more than 1000 m thick, of alluvial deposits, which run from proximal alluvial conglomerates in the N and NW to distal alluvial flats and lacustrine basins towards the S and SE. According to Ramos et al. (2001), the lakes in the distal alluvial system of the Cala Blanca Fm were smaller than the Peguera lakes and richer in siliciclastic inputs. The Cala Blanca lacustrine basins also developed under a warm and humid climate, with a rhythmic sedimentation suggesting a certain seasonality. They were perennial, open, freshwater carbonate lakes, with important carbonate production and organic matter contribution. Previous data on the age of this formation were based on a rich mammal assemblage from Sineu reported by Forsyt-Major (1904), Vidal (1905) and Huguency and Adrover (1989-90). These last two authors considered the fauna was Late Oligocene in age.

A number of sections and boreholes yielded charophyte remains from the non-marine formations of the Balearic Islands and are described below.

### Santa Ponça-Peguera

The sea-cliff between the Cala de Sta. Ponça (Sta. Ponça bay) and Peguera beach (Figs. 1 and 2) shows a complete Palaeogene sedimentary record for more than 2.5 km. The succession crops out in the flanks of kilometric folds with SW-NE axis and verging to the NW (Fig. 2A). The study of a set of partial logs led to the proposal of a composite type-section for the non-marine Palaeogene of SW Mallorca (Ramos-Guerrero, 1988), which includes the type-section of the Peguera Limestone Fm and a good section of the Cala Blanca Detrital Fm. These units contain charophytes (Table 1) and are separated by a thin conglomerate interval, which constitutes the westernmost record of the marine Alaró Fm.

### Cala Blanca

Cala Blanca is a small bay located about 3 km west of Peguera beach (Figs. 1 and 3A). Palaeogene rocks crop out, forming part of the East and West sides of the bay. Most of the outcropping succession belongs to the alluvial deposits of the Cala Blanca Detrital Fm. However, on the western side, the uppermost 35 m of the Peguera Fm occur and yielded one sample with charophyte remains (Fig. 3B and Table 1).

TABLE 1 | Charophyte assemblages of non-marine Palaeogene samples from the Balearic Islands.

Lithostratigraphy	Peguera Limestone Fm										Cala Blanca Detrital Fm					
	Sta. Ponça-Peguera			Cala Blanca	Cala d'Egos			Alaró			Es Macar de sa Llosa		Sineu	Sta. Ponça-Peguera		
	PP.54	PP.11	01.0.10	B.14	01.5.03	01.5.06	01.5.07	Core 13.1	Core 5.1	S.1-33	S.1-35	14.1.07	14.1.08	9.1-1	PP.08	01.0.45
Species	Samples															
<i>Maederiaella marginoti</i>		●	●													
<i>Maederiaella serialis</i>			●	●												
<i>Harrisichara caeciliana</i>	●	●			●	●	●									
<i>Harrisichara vasiformis-tuberculata</i>								●								
<i>Nitellopsis</i> sp.														●		
<i>Nitellopsis (Tectochara) aemula</i>								●								
<i>Gyrogonia</i> sp. 1			●													
<i>Gyrogonia</i> sp. 2									●	●						
<i>Lychnothamnus praelangeri</i>															●	
<i>Lychnothamnus langeri</i>														●		
<i>Lychnothamnus stockmansii</i>												●	●			
<i>Sphaerochara himeri</i>																●
<i>Sphaerochara inconspicua</i>												●	●			
<i>Sphaerochara</i> sp.								●								
<i>Raskyella peckii</i> subsp. meridionale	●		●													

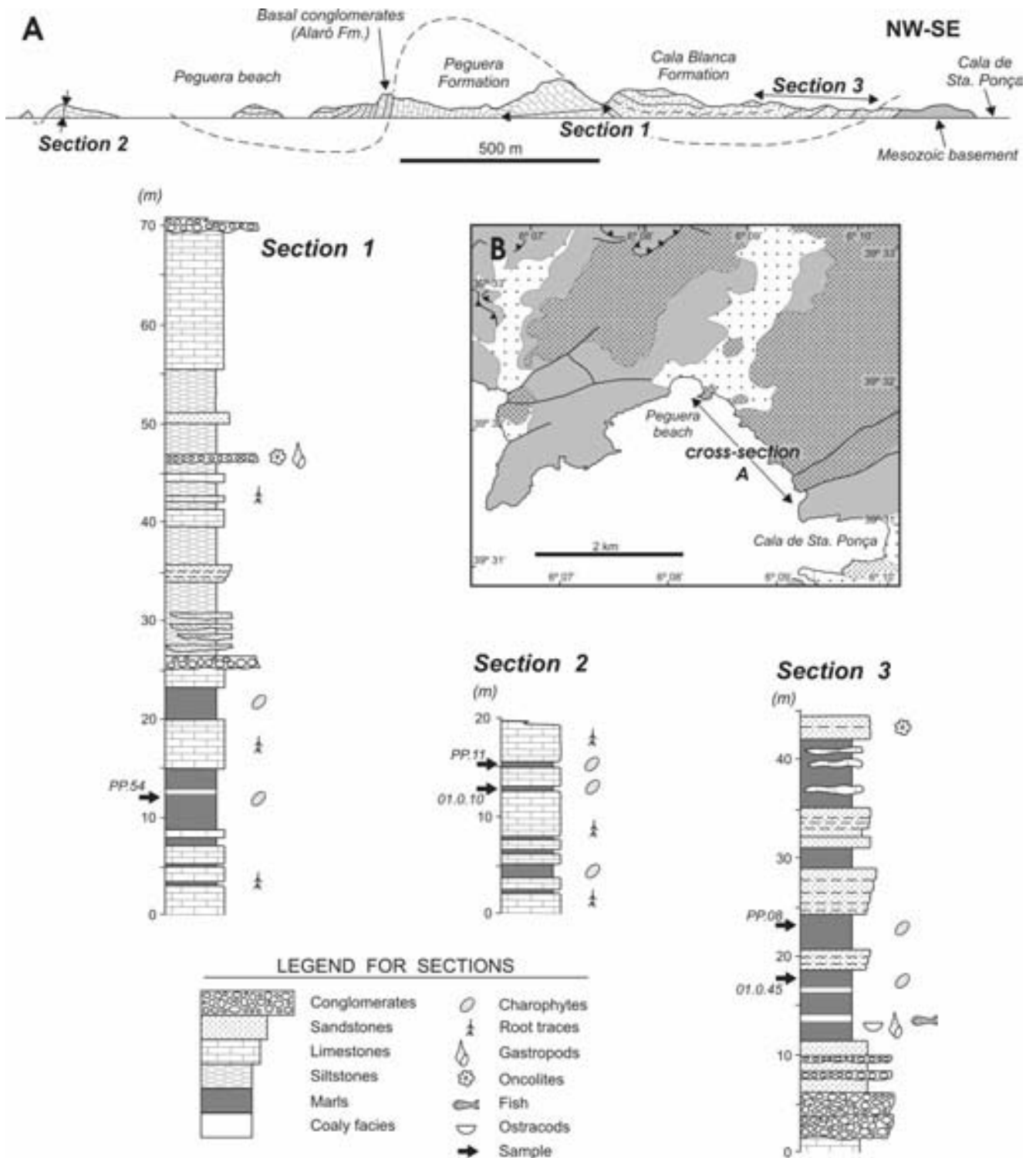


FIGURE 2 | Location and stratigraphic logs of the Sta. Ponça-Peguera section. A) Cross-section along the Sta. Ponça-Peguera sea-cliff and stratigraphic logs with position of charophyte samples. B) Geological map of the area and location of the cross-section A. Modified from Ramos-Guerrero (1988).

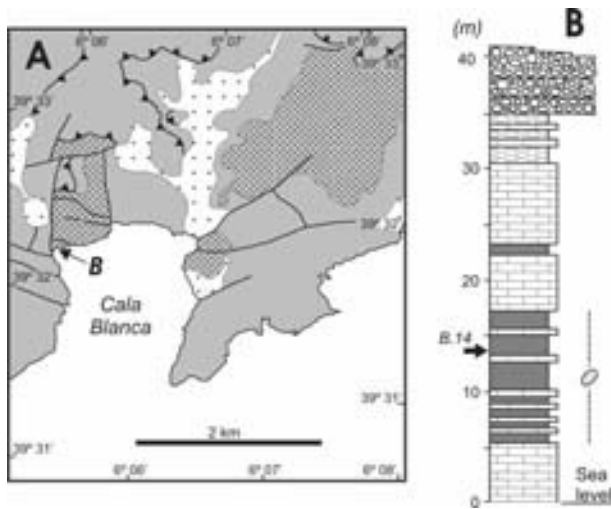


FIGURE 3 | Location and stratigraphic log of the Cala Blanca section. A) Geological map and location of the studied section. Legend as in Fig. 1A (after Ramos-Guerrero, 1988). B) Partial stratigraphic log of the lower 40 m of the Cala Blanca section with location of charophyte sample. Legend as in Fig. 2.

### Cala d'Egos

This includes part of the westernmost Palaeogene outcrops of the Balearic Islands (Fig. 1A). Cala d'Egos is a small bay located 2 km to the West of Port d'Andratx (Fig. 4A). The western side of the bay shows a 60 m thick Palaeogene succession bounded by normal faults. The lower 40 m of this succession belong to the Peguera Fm. (Fig. 4B), and delivered three samples that yielded a monospecific charophyte flora (Fig. 4B and Table 1).

### Alaró boreholes S.1 and 13-1

Alaró is a small coal mining-town located on the NW of Mallorca (Fig. 1A). A number of sub-surface data,

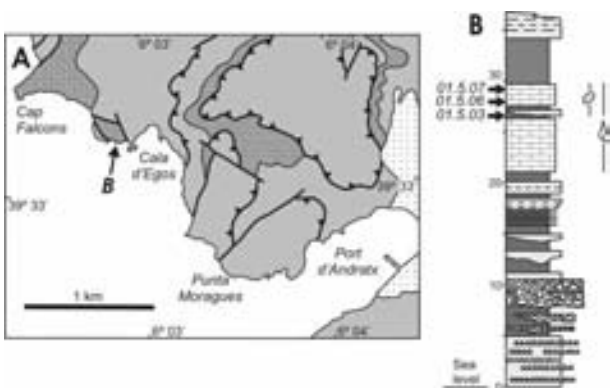


FIGURE 4 | Location and stratigraphic log of the Cala d'Egos section. A) Geological map and location of the studied section. Legend as in Fig. 1A (after Ramos-Guerrero, 1988). B) Partial stratigraphic log of the lower part of the Cala d'Egos section with location of the samples. Legend as in Fig. 2.

including samples from two borehole cores (13.1 and S.1), were available for study (Fig. 5).

Data of borehole 13.1 were supplied by Oliveros et al. (1960a). The 309.6 m deep well penetrates 220.0 m of the Cala Blanca and Alaró Fms and 87.6 m of the Peguera Fm (between 220.0 to 307.6 m deep). The lowermost 2 meters cut into Cretaceous (Albian) rocks. One sample (13.1-1) of grey massive marl in the Peguera Fm. yielded charophyte remains (Oliveros et al., 1960a, pp. 128-129) and is located between 270 and 272 m deep (Fig. 5B and Table 1).

Borehole S.1 was described by Ramos-Guerrero (1988). It is a 149.6 m deep well which cuts the Peguera Fm to the depth of 147.5 m. The bottom 2.1 m (from 147.5 to 149.6 m) are Cretaceous rocks. Two samples of laminated limestones, S.1-33 and S.1-35, yielded charophyte remains at 130.8 and 138.6 m depth, respectively. A log of borehole S.1 interval containing these samples is shown in Fig. 5C, and the charophyte content in Table 1.

### Sineu borehole 9.1

The borehole is located 1.5 km to the North-west of Sineu (Figs. 1A and 5D). The description by Oliveros et al. (1960b) indicates that it is a 373.75 m deep well entirely bored through the Cala Blanca Detrital Fm. A core sample, called 9.1-1, was taken by Oliveros et al. (1960b, p.166) in laminated black marls and coal at 187.0-187.5 m depth, and yielded charophyte remains (Fig. 5E and Table 1).

### Es Macar de sa Llosa

The sea-cliffs of Es Macar de sa Llosa, on the north coast of Menorca (Figs. 1A and 6A) contain a 40 m thick section of the Cala Blanca Fm (Fig. 6B). The succession consists of coarse conglomerates and breccias, but at the top massive grey-to-white marls supplied two samples containing charophyte remains (Fig. 6B, Table 1).

## SYSTEMATIC PALAEOLOGY

**Division:** Charophyta MIGULA, 1897

**Class:** Charophyceae SMITH, 1938

**Order:** Charales LINDLEY, 1836

**Family:** Characeae RICHARD ex C. AGARDH, 1824

GENUS *Maedleriella* GRAMBAST, 1957

*Maedleriella mangeloti* GRAMBAST, 1957

Figures 7A to 7D

1957 *Maedleriella mangeloti* n. sp., Grambast, pp. 12-14, text-figs. 3-4, pl. 7, figs. 7-14.

1969 *Maedleriella mangeloti* Grambast, Castel and Grambast, pp. 940, pl. 31, figs. 8-9.

1986 *Maedleriella mangeloti* Grambast, Riveline, pp. 50, pl. 18, figs. 1-3.

*Material:* About 550 gyrogonites from samples PP.11 and 01.0.10, Santa Ponça – Peguera (Mallorca).

*Description:* Medium to large gyrogonite, 550-785 µm high (mean 665 µm) and 595-890 µm wide (mean 732), sub-spherical to slightly depressed in shape with an isopolarity index (ISI) ranging 80-100 (mean 90). Spiral cells 95-165 µm wide and ornamented with aligned nodules, with 6-8 (most frequently 7) convolutions visible in lateral view. Apex flat or rounded, without peri-apical depression or shortening in spiral cells, but often bearing apical nodules that form a distinct rosette. Base normally flat. A prismatic single-celled basal plate, 80-135 µm across, is visible from the outside and sometimes bears a nodule.

The ornamentation allowed us to distinguish five morphotypes: (1) Gyrogonites with heavily calcified, convex, spiral cells; intercellular sutures in furrows; large and rounded nodules, separated by spaces as long as one nodule (Fig. 7A). (2) Gyrogonites with flat spiral cells separated by prominent intercellular sutures; nodules warty, separated by spaces larger than one nodule (Fig. 7B). (3) Gyrogonites bearing spiral cells similar to previous morphotype; displaying intercalation of large and small nodules. (4) Spiral cells as previous type with nodules aligned close to each other, almost fused. (5) Gyrogonites poorly calcified, spiral cells separated by prominent sutures; nodules shallow, slightly higher than the intercellular sutures and separated as in morphotypes 2 or 4 (Fig. 7C).

*Discussion:* The most abundant morphotypes in the populations studied from Mallorca are the first and second, which justifies their specific attribution. Other morphotypes could be attributed to closely related species such as *M. intermedia* SOULIÉ-MÄRSCHÉ, 1974 (morphotype 3) and *M. embergeri* GRAMBAST, 1958 or even *M. funiculosa* FEIST-CASTEL 1970 (morphotype 4), a situation which frequently occurs, as already noticed by Soulié-Märsché (1974), Riveline (1986) and Martín-Closas (1991). This last author compared the four species and concluded that they should be considered synonyms.

*Maedleriella serialis* FEIST in Anadón et Feist, 1981  
Figure 7E

1981 *Maedleriella serialis* n. sp., Feist in Anadón and Feist, pp. 155-156, pl.1, figs. 8-12; pl. 3, fig. 1, text-fig. 5.

1999 *Maedleriella serialis* Feist, 1981, Martín-Closas et al., p. 10, figs. 6.9-6.12.

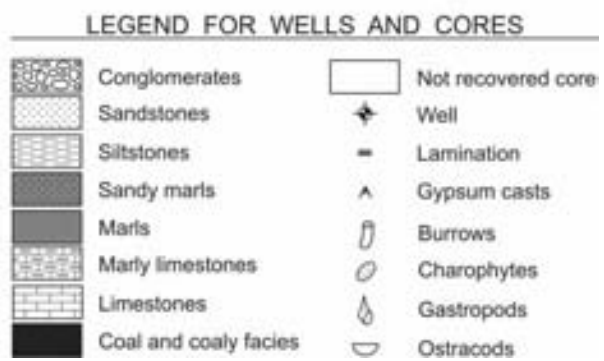
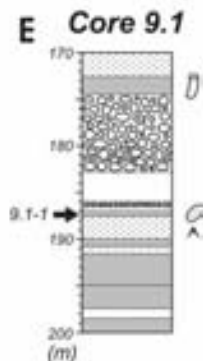
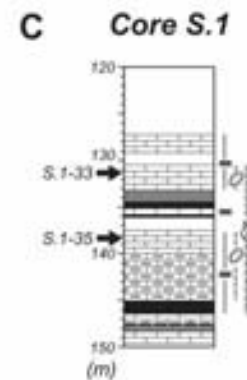
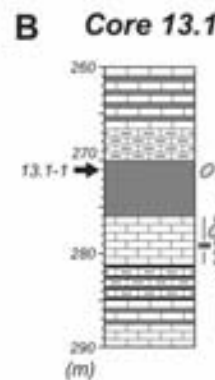
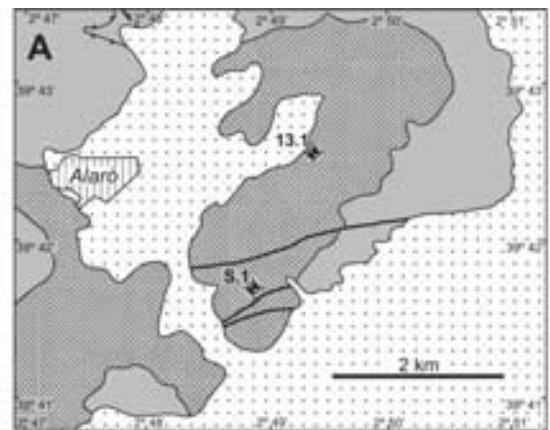


FIGURE 5 | Location and stratigraphic logs of boreholes from Alaró and Sineu. A) Geological map showing location of the boreholes S.1 and 13.1. B) and C) Partial stratigraphic logs and position of samples in boreholes S.1 and 13.1 respectively. D) Geological map showing location of borehole 9.1. E) Partial stratigraphic log of borehole 9.1. Log 13.1 after Oliveros et al. (1960a). Log 9.1 after Oliveros et al. (1960b).

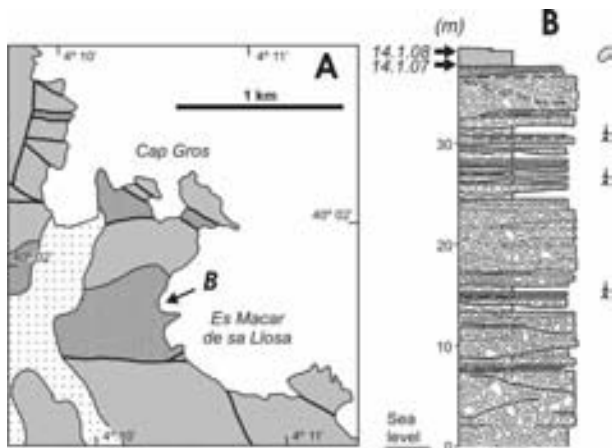


FIGURE 6 | Location and stratigraphic log of Es Macar de sa Llosa (Menorca). A) Geological map and location of the studied section (after Ramos-Guerrero, 1988). Legend as in Fig. 1A. B) Stratigraphic log of the Cala Blanca Detrital Fm outcropping in sea-cliffs. Legend as in Fig. 3.

**Material:** About 110 gyrogonites from sample B.14 from Cala Blanca and 90 gyrogonites from sample 01.0.10 from Santa Ponça – Peguera (Mallorca).

**Description:** Gyrogonites small, 460-650  $\mu\text{m}$  high (mean 565  $\mu\text{m}$ ) and 595-700  $\mu\text{m}$  wide (mean 645  $\mu\text{m}$ ), depressed (oblate) in shape, with an isopolarity index ranging from 76-109 (mean 87). Apex and base flat. Spiral cells 80-110  $\mu\text{m}$  in width. Seven or eight convolutions visible in lateral view. Ornamentation formed of a tight succession of small nodules, which are arranged along the central line of spiral cells and may form an irregular crest, much higher than cell sutures. Apical nodules may be absent or prominent. Basal plate visible from the outside when provided with a nodule.

**Discussion:** In comparison to the type material from the Ebro basin (Anadón and Feist, 1981) the Balearic *Maedleriella serialis* is more oblate, which is due to its greater width.

#### GENUS *Harrisichara* GRAMBAST, 1957

##### *Harrisichara caeciliana* SOULIÉ-MÄRSCHÉ, 1974 Figures 7F to 7I

- 1958 *Harrisichara brevipes* n. sp. (nomen nudum), Grambast, p. 107, figs. a,b.  
 1958 *Harrisichara margaritifera* n. sp. (nomen nudum), Grambast, p. 97, figs. 31 a,b,c.  
 1972a *Harrisichara brevipes* (nomen nudum), Grambast, p. 107, figs. a and b.  
 1974 *Harrisichara caeciliana* n. sp., Soulié-Märsche, pp. 127-130, fig. 9, pl. 4.  
 1981 *Harrisichara* aff. *brevipes* Grambast (nomen

nudum), Feist in Anadón and Feist, pp. 158-159, pl. 4, fig. 7.

- 1981 *Harrisichara caeciliana* Soulié-Märsche, Feist in Anadón and Feist, pp. 159-160, pl. 4, fig. 8.  
 1986 *Harrisichara brevipes* Grambast (nomen nudum), Riveline, pp. 34, 37, table 7, pl. 7, figs. 1-3.  
 1986 *Harrisichara margaritifera* Grambast (nomen nudum), Riveline, p. 37, table 7, pl. 6, figs. 9-12.  
 1991 *Harrisichara caeciliana* Soulié-Märsche 1974, var. *caeciliana* var. nom., Martín-Closas, pp. 226-233, pl. 2, figs. 1-8.

**Material:** About 250 gyrogonites from samples PP.11 and 01.0.10 from Santa Ponça – Peguera (Mallorca) and 270 gyrogonites from samples 01.5.03, 01.5.06 and 01.5.07 from Cala d'Egos (Andratx, Mallorca).

**Description:** Gyrogonites sub-spherical, medium-to-large in size, 730-1110  $\mu\text{m}$  high (mean value 925  $\mu\text{m}$ ) and 675-1029  $\mu\text{m}$  wide (mean value 895  $\mu\text{m}$ ). Isopolarity index ranges from 90-125 (mean value 104). Eight to eleven, most frequently nine, convolutions visible in lateral view. Spiral cells 80-135  $\mu\text{m}$  wide, ornamented with closely arranged tubercles and separated by prominent sutures. In the samples from Santa Ponça-Peguera large tubercles alternate with smaller ones, whilst in the Cala d'Egos population the tubercles are similar in size, normally joined by a small central crest. Apex flat and devoid of ornamentation, but some gyrogonites show slightly marked, comma-shaped apical nodules. Base rounded, normally without a column but some specimens bear a short, prismatic column. Basal pore large and pentagonal, 55-135  $\mu\text{m}$  in diameter.

**Discussion:** A number of authors including Riveline (1986, Table 7) and Martín-Closas (1991) compared at least three species of *Harrisichara* from the Middle Eocene: *H. brevipes*, *H. caeciliana* and *H. margaritifera*. The three are similar in size and shape but differ in details of their ornamentation and the size of their short basal column, both features being very variable intra-population. *H. brevipes* displays an alternation of small and large, closely arranged tubercles and the basal column is usually absent or only poorly developed in some specimens. The apex is devoid of ornamentation. *H. caeciliana* has well individualised tubercles, all of about the same size, which may be communicated by a mid-crest. The basal column is short, but normally present in the populations. The apex shows poorly-marked, comma-shaped nodules. Though *H. margaritifera* is similar to *H. caeciliana* in the arrangement of tubercles and basal column, it has more prominent tubercles both along the spiral cells and at the apex. The populations of Santa Ponça-Peguera are very similar to the form *brevipes*, i.e. with alternating small and large tubercles, whereas the orna-



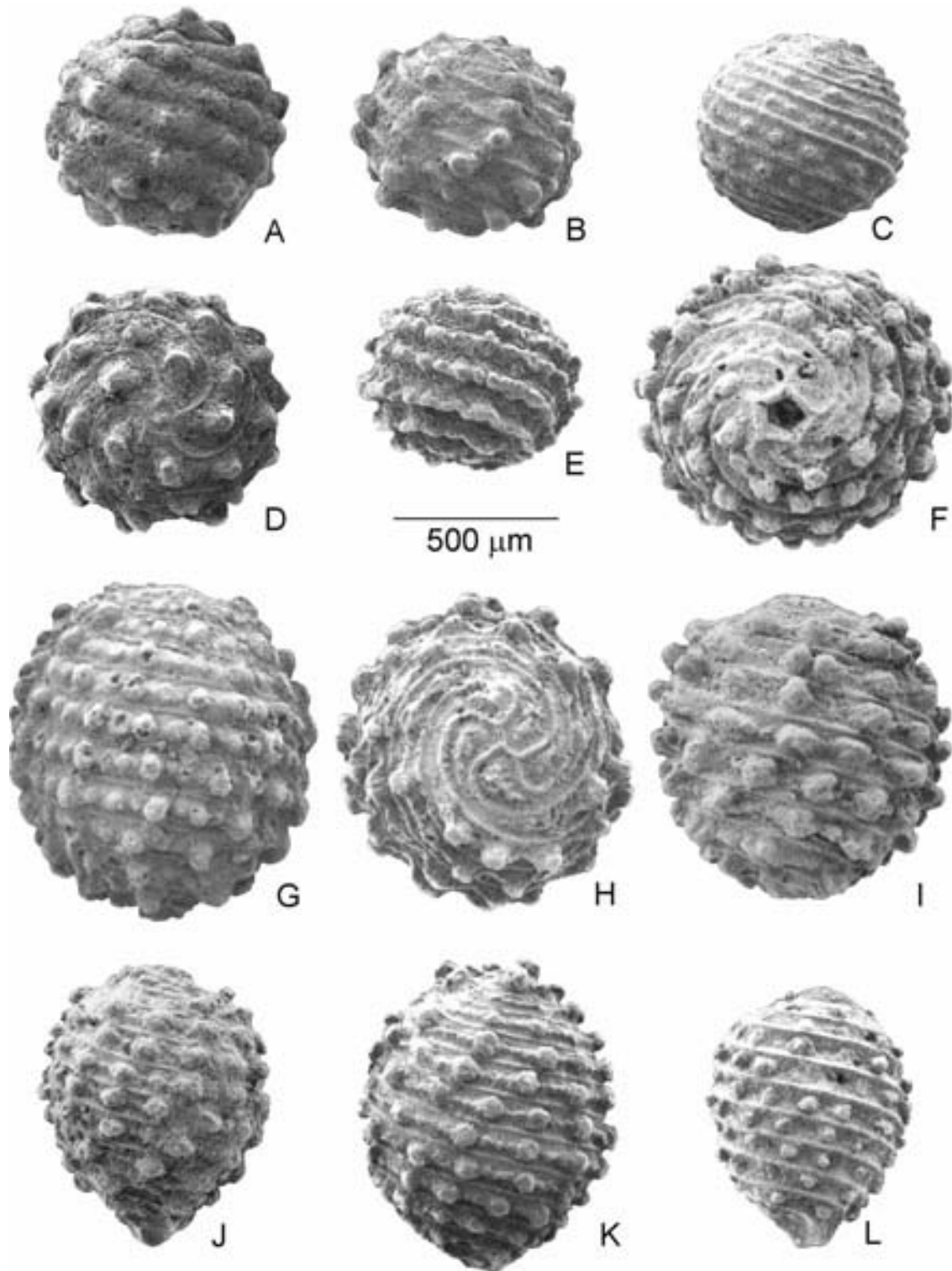


FIGURE 7 | Gyrogonites of genera *Maedleriella* and *Harrisichara*. A to D) *Maedleriella manganoti*, sample O1.0.10. A and C) lateral views, D) base. E) *Maedleriella serialis*, O1.0.10, lateral view. F to I) *Harrisichara caeciliana*, sample PP.11, F) base, G and I) lateral views, H) apex. J to L) *Harrisichara vasiformis-tuberculata*, borehole 13.1., lateral views.

mentation of the populations of Cala d'Egos populations are more like the form *caeciliana*. Martín-Closas (1991) reported that the three forms may coexist in the same sample, though in different proportions and showing intermediate forms. In consequence, he proposed that they be con-

sidered synonymous. In addition neither *H. brevipes* nor *H. margaritifera* are valid species according to the rules of the International Code of Botanic Nomenclature, since they lack a validly published holotype and a formal diagnosis.

***Harrisichara vasiformis-tuberculata*** FEIST-CASTEL, 1977  
 Figures 7J to 7L

- 1977a *Harrisichara vasiformis-tuberculata*, Feist-Castel, p. 152, pl. 21, figs. 2-3.  
 1986 *Harrisichara "vasiformis-tuberculata"*, Rive line, p. 38, pl. 7, fig. 11.

**Material:** 21 gyrogonites in sample 13.1-1 from borehole 13.1 (Alaró, Mallorca).

**Description:** Gyrogonites large, 725-940 µm (often 800-900 µm) high and 625-785 µm (often 650-725 µm) wide, ellipsoidal or oval in shape with an isopolarity index of 105-130 (average 120). Apex rounded. Base conical or elongated in a small column. Spiral cells flat or concave, 75-125 µm in width. Nine to eleven convolutions are visible laterally. The ornamentation consists of regularly spaced tubercles, which may be joined by a fine central crest. Apical tubercles are present in a few specimens.

**Discussion:** In 1959, Grambast attributed this population to *H. tuberculata* as reported by Colom (1983, p. 144: figs. 5.1-5.12, pl. 9: fig. 2). At the time of Grambast's identification the existence of transitional forms between *H. tuberculata* and *H. vasiformis* was unknown. These were informally described by Feist-Castel (1977a) as *H. vasiformis-tuberculata*, which is the name still in use. The three species constitute *de facto* a continuum of forms (Sille et al., 2004), which means that the whole lineage corresponds to a single evolutionary species in Wiley's (1981) definition. However, as a revision of the Characeae as a whole is beyond the scope of this study, the Mallorcan population is attributed to *H. vasiformis-tuberculata* solely on the basis of its morphological affinity.

GENUS *Nitellopsis* HY, 1889

**Subgenus:** *Tectochara* L. et N. GRAMBAST, 1954

***Nitellopsis (Tectochara) aemula*** (GRAMBAST, 1972) nov. comb. GRAMBAST et SOULIÉ-MÄRSCHÉ, 1972  
 Figures 8A to 8C

- 1972b *Tectochara meriani* L. et N. Grambast s. sp. *aemula*, Grambast, p. 23, fig. 10; pl. 8, figs. 1-6.  
 1972 *Nitellopsis (Tectochara) aemula* (Grambast), Grambast and Soulié-Märsche, p. 11.  
 1977a *Nitellopsis (Tectochara) aff. aemula* Grambast, 1972, Feist-Castel, p. 146, pl. 22: figs. 4a-4c.  
 1986 *Nitellopsis (Tectochara) aemula* Grambast, Riveline, p. 28, pl. 3: figs. 5-8.

**Material:** Ten, well-preserved gyrogonites were available for study from a core sample 270-272 m deep in borehole 13.1 (Alaró, Mallorca).

**Description:** Gyrogonite very large, 1110-1445 µm high and 915-1255 wide, pear-shaped with an isopolarity index (ISI) ranging from 110-125. Apex prominent, with apical nodules forming a rosette. Base elongated in a truncated cone. Basal pore pentagonal, 120-290 µm in diameter, located within a marked basal funnel. Spiral cells flat or slightly convex, 170-215 µm wide and forming 8-9 convolutions in lateral view. Strong shortening and thinning of spiral cells occur around the apical rosette. There are no modifications of the spiral cells near the base. Ornamentation absent, except near the apical zone, where poorly marked nodules occur.

**Discussion:** This population clearly belongs to the group of taxa related to *Nitellopsis (Tectochara) meriani*, i.e. non-ornamented *Tectochara*-type gyrogonites with an elongated base. A number of the former subspecies of this taxon were raised to the specific level by Grambast and Soulié-Märsche (1972) on the basis of phenetic, non-phylogenetic criteria. These are *N. (T.) aemula* (GRAMBAST, 1972) GRAMBAST et SOULIÉ-MÄRSCHÉ, 1972, *N. (T.) globula* (MÄDLER, 1955) GRAMBAST et SOULIÉ-MÄRSCHÉ, 1972, *N. (T.) helvetica* (MÄDLER, 1955) GRAMBAST et SOULIÉ-MÄRSCHÉ, 1972 and *N. (T.) huangi* (LU, 1945) GRAMBAST et SOULIÉ-MÄRSCHÉ, 1972. The taxonomy of this group would have to be revised to match current taxonomy to a phylogenetic system for Characeae, but this is beyond the scope of our study. Thus, the Mallorcan material is attributed to *N. (T.) aemula* solely on the basis of morphological affinity. This taxon differs from *N. (T.) meriani meriani* because of the shape of the base, which is more elongated in *N. (T.) aemula*. *N. (T.) helvetica* is smaller than the population studied. Finally, *N. (T.) globula* and *N. (T.) huangi* differ in their general shapes. The first is more spheroidal and the second more elongated than our material, respectively.

The charophytes referred to as *N. (T.) meriani* by Colom (1983, p. 52: fig. 6 and plate 9: fig. 2) are probably equivalent, at least in part, to the material described. However, the drawings of this author show more globular gyrogonites with poorly developed apical nodules.

***Nitellopsis* sp.**

A few gyrogonites were found in sample 9.1-1 from borehole 9.1 (Sineu, Mallorca). The generic characters were present, but the small number of specimens prevents more detailed taxonomy.

GENUS *Gyrogona* LAMARCK, 1822 emend. GRAMBAST, 1956

***Gyrogona* sp. 1**

**Material:** Only 2 gyrogonites available from sample 01.0.10 at Santa Ponça-Peguera (Mallorca).

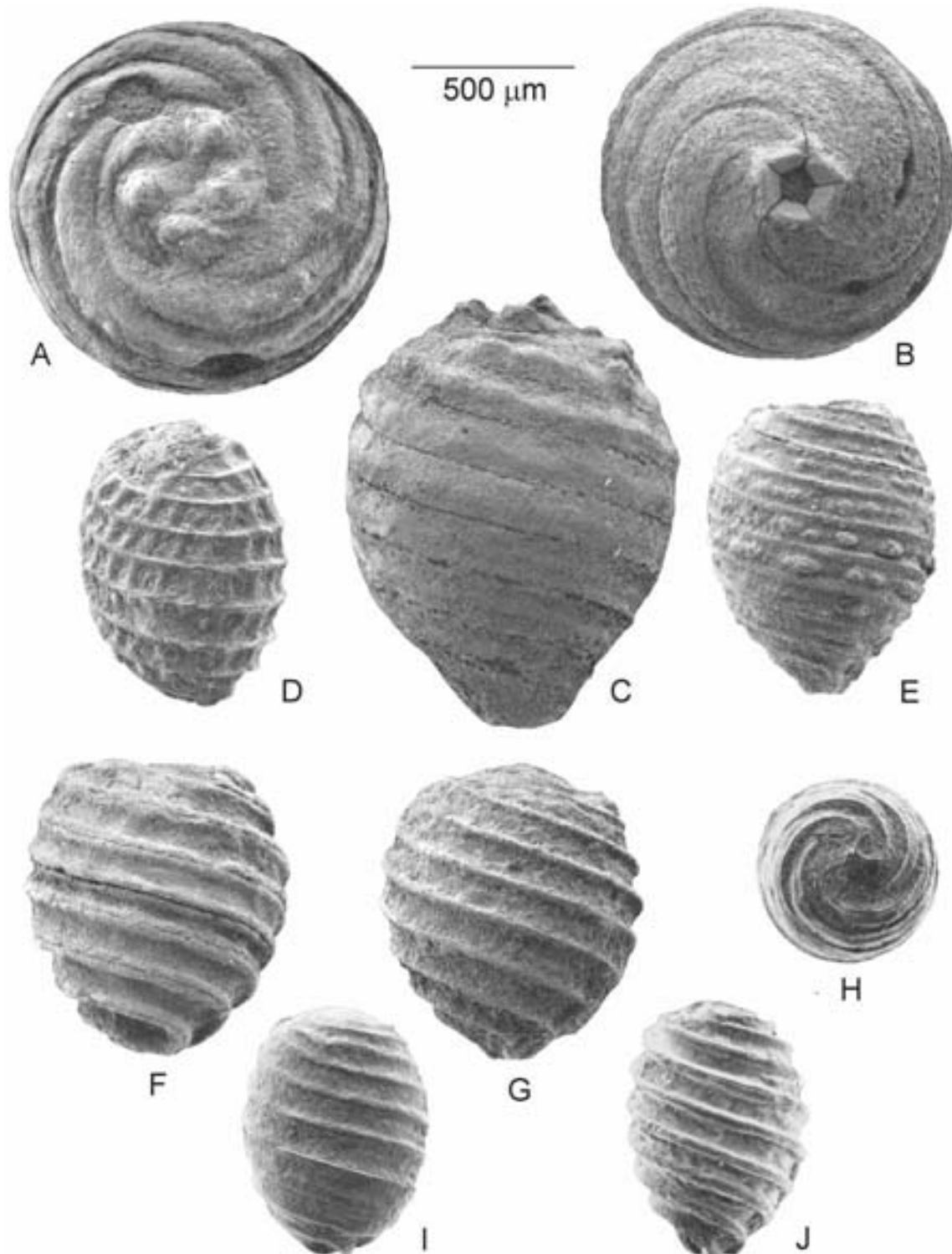


FIGURE 8 | Gyrogonites of genera *Nitellopsis* and *Lychnothamnus*. A to C) *Nitellopsis* (*Tectochara*) *aemula*, borehole 13.1, A) apex, B) base, C) lateral view. D) *Lychnothamnus langeri*, borehole 9.1, lateral view. E to G) *Lychnothamnus praelangeri*, sample PP.08, all lateral views. H to J) *Lychnothamnus stockmansi*, sample 14.1.08, H) apex, I and J) lateral views.

*Description:* Gyrogonites large, 940-1035 µm high and 930-965 µm wide, sub-spheroidal in shape, with an isopolarity index ranging from 101-107. Apex flat with periapical depression. Base slightly pointed. Spiral cells

convex, 145 µm in width. Nine convolutions visible laterally. Sutures simple. Ornamentation poorly marked, formed by large and flat nodules quite separate from each other, almost disappearing around the apex.

*Discussion:* The small number of gyrogonites prevents more detailed definition.

### ***Gyrogona* sp. 2**

*Material:* Twelve gyrogonites available from samples S.1-33 and S.1-35 from borehole S.1 (Alaró, Mallorca). Most of them are poorly preserved, probably reworked.

*Description:* Gyrogonite large, 750-875 µm high and 775-975 µm wide, depressed (oblate) in shape with an isopolarity index (ISI) of 85-100. Apex and base flat. Spiral cells convex, 145 – 180 µm in width. Six convolutions visible in lateral view. Ornamentation is variable: about 50% of the population displays large nodules, which take up the whole width of the spiral cell, whereas the other half shows smaller nodules, more or less fused along a medial line of spiral cells. The sutures that are visible are simple. Apical nodules form a distinct rosette due to the periapical thinning of the surrounding spiral cells.

*Discussion:* The population studied has similarities with *Gyrogona medicaginula*, *G. wrighti* and *G. moreletii*. More material and a better preservation are needed for more accurate determination.

GENUS *Lychnothamnus* (RUPRECHT, 1845) LEONHARDI, 1863 emend. A. BRAUN in BRAUN et NORDSTEDT, 1882

*Remark:* We place in this genus three species traditionally assigned to genus *Rhabdochara* MÄDLER, 1955 emend. GRAMBAST, 1957. Comparative studies between extant and fossil gyrogonites undertaken by Soulié-Märsche (1989, pp. 154-161) and additional data provided by Soulié-Märsche and Martín-Closas (2003) confirm that genus *Rhabdochara* is a junior synonym of genus *Lychnothamnus*.

*Lychnothamnus praelangeri* (CASTEL, 1967) n. comb. SOULIÉ-MÄRSCHÉ, 1989.  
Figures 8E to 8G

- 1967 *Rhabdochara praelangeri* nov. sp., Castel, pp. 516-517, pl. 20, fig. 1-11.  
1977b *Rhabdochara praelangeri* Castel, Feist-Castel, p. 126, pl. 5, fig. 14.  
1986 *Rhabdochara praelangeri* Castel, Riveline p. 58, pl. 20, fig. 10-11.  
1989 *Lychnothamnus praelangeri* (Castel) nov. comb., Soulié-Märsche, p. 160.

*Material:* 70 gyrogonites were available from sample PP.08 (Santa Ponça-Peguera, Mallorca).

*Description:* Gyrogonites were large, 810-1000 µm high (mean 890 µm) and 675-840 µm wide (mean 760 µm), and ovoidal in shape. The isopolarity index ranges from 100-127 (mean 117). The apex is truncated and shows thinning. Base rounded, conical or pointed, showing a pentagonal or star-shaped basal pore within a short funnel. Spiral cells 55-110 µm wide, flat to concave and separated by prominent, sometimes bicarinated sutures. About 8-9 convolutions are laterally visible. Ornamentation may be absent or consist of small, rounded nodules, irregularly distributed in spiral cells.

*Discussion:* The specimens from the population studied here are somewhat larger than the type material. The ornamentation is similar to that in the morphotypes with small granules described by Castel (1967) for *Rhabdochara praelangeri*. This species is easily distinguished from other ornamented *Lychnothamnus* (including *Rhabdochara*) by the shape and features of its ornamentation.

*Lychnothamnus langeri* (ETTINGSHAUSEN, 1872) n. comb. SOULIÉ-MÄRSCHÉ, 1989.  
Figure 8D

- 1872 *Chara langeri* n. sp., Ettingshausen C. von, p. 162, pl. I, figs. 2-4 and 4b.  
1955 *Rhabdochara langeri* (Ettingshausen) nov. comb., Mädler, p. 299, pl. 26, figs. 25-27.  
1957 *Rhabdochara langeri* (Ettings.) Mädler, Grambast, p. 16, text-fig. 7, pl. VIII: fig. 9.  
1959 *Rhabdochara langeri* (Ettingshausen, 1872) Mädler 1955, Horn af Rantzien, p. 140, pl. 17: figs. 1-6.  
1962 *Rhabdochara langeri* (v. Ettingshausen) Mädler, Nötzold, p. 666, pl. 6, figs. 1-5.  
1962 *Rhabdochara langeri* (v. Ettingshausen) Mädler ssp. *tuellengensis* n. ssp., Nötzold, p. 667, p. 4, figs. 5-9.  
1977 *Rhabdochara langeri* (Ettingshausen) Mädler 1955, Feist and Ringede, p. 350, pl. 13, figs. 8-9.  
1983 *Rhabdochara langeri* (Ettingshausen) Mädler 1955, Berger, p. 16, fig. 3, num. 7, pl. 2, figs. 10-12.  
1989 *Lychnothamnus langeri* (Ettingshausen) nov. comb., Soulié-Märsche, p. 159.

*Material:* 28 compressed gyrogonites in sample 9.1-1 from borehole 9.1 (Sineu, Mallorca).

*Description:* Gyrogonite large, 950-1100 µm high and 650-1000 µm wide, ellipsoidal in shape. Apex rounded and devoid of ornamentation. Base pointed. About nine convolutions are visible in lateral view. Spiral cells are

concave, 80-135 µm in width, and bear a characteristic ornamentation of small sticks perpendicular to sutures and spaced at regular intervals. Intercellular sutures are prominent.

*Discussion:* The unique ornamentation of this species allows identification even of poorly preserved materials, such as the specimens from borehole 9.1. The species was already reported and drawn by Colom (1983, p. 24, fig. 1) from the same core samples.

*Lychnothamnus stockmansii* (GRAMBAST, 1957) n. comb. SOULIÉ-MÄRSCH, 1989.

Figures 8H to 8J

- 1957 *Rhabdochara stockmansii* n. sp., Grambast, pp. 17-18, text-fig. 6, pl. VIII, figs. 10-14.  
 1977a *Rhabdochara stockmansii* Grambast, 1957, Feist-Castel 1977, p. 154.  
 1977 *Rhabdochara stockmansii* Grambast 1977, Feist and Ringeade, p. 350.  
 1986 *Rhabdochara stockmansii* Grambast, Riveline, p. 57, pl. 21: figs. 6-9.  
 1989 *Lychnothamnus stockmansii* (Grambast) nov. comb., Soulié-Märsche, p. 160.

*Material:* Eight gyrogonites in samples 14.1.07 and 14.1.08, from Es Macar de sa Llosa (Menorca).

*Description:* Gyrogonites large, 745-845 µm high and 580-650 µm wide (average 750 x 600), ellipsoidal to ovoidal, with an isopolarity index of 115-145 (average 125). Apex rounded to truncated, showing apical thinning. Base slightly rounded to pointed. Basal pore 60-70 µm in diameter, superficial or within a small funnel. Spiral cells flat to concave, 100-120 µm at maximum width, separated by prominent sutures which are sometimes bicarinated. Laterally 8-9 convolutions are visible.

*Discussion:* The population of Menorca is slightly smaller than the type material, but the other features are the same. This species is similar to *Rhabdochara krauseli* (RASKY, 1945) GRAMBAST, 1957, which is somewhat larger (height above 800 µm) and more elongated in shape. The population of Menorca differs from other Balearic species of *Lychnothamnus* in its size and absence of ornamentation.

GENUS *Sphaerochara* MÄDLER, 1952 emend. HORN AF RANTZIEN et GRAMBAST, 1962

*Sphaerochara hirmeri* (RASKY, 1945) MÄDLER, 1952

Figures 9A to 9E

- 1945 *Chara hirmeri* n. sp., Rasky, p. 36, pl. 1, figs. 10-12.

- 1952 *Chara hirmeri*, Mädlér, p. 6.

- 1959 *Sphaerochara hirmeri* (Rasky, 1945) Mädlér 1952, Horn af Rantzien, p. 130, pl. 16, figs. 1-4.

- 1986 *Sphaerochara hirmeri* (Rasky) Mädlér, Riveline, p. 78, pl. 35, figs. 8-10.

*Material:* About 100 gyrogonites available from sample 01.0.45 at Santa Ponça-Peguera (Mallorca).

*Description:* Gyrogonites spheroidal, 375 - 475 µm high and 325-450 µm wide, with an isopolarity index (ISI) ranging between 100-120 (75% between 100-110). Seven to nine convolutions are visible laterally. The apex is rarely preserved and shows no modifications at the level of spiral cell junctions. Apical nodules were not found. The basal plate is pentagonal and large, about 50-70 µm in diameter. It is clearly visible from the outside and bears a nodule in some specimens. The ornamentation of spiral cells is variable. About one third of the population shows concave spiral cells with protruding sutures but without nodules. The rest has elongated nodules distributed irregularly in the central part of the spiral cells. Heavily ornamented gyrogonites show different degrees of fusion between nodules.

*Discussion:* The population studied is closest to *S. hirmeri* but has affinities with a number of other species of the genus as well. In comparison to the type material of *S. hirmeri* described by Rasky (1945) and Horn af Rantzien (1959), the Mallorcan population is somewhat smaller, since its greater heights correspond to the smallest heights of the type population. Another difference concerns the number of convolutions, over 10 in the type population, whereas our material does not reach that figure. Nevertheless, the Mallorcan material is very similar to the type material in the ornamentation of most gyrogonites. *Sphaerochara granulifera* (HEER, 1855) MÄDLER 1955 is very close to the material studied in dimensions, shape and number of convolutions, but differs in the ornamentation since this species shows convex cells but does not display nodules. In addition *S. headonensis* (REID et GROVES, 1921) HORN AF RANTZIEN, 1959 is similar to the studied population in almost all characters except in the calcification of spiral cells, which are concave. From the ornamented species of *Sphaerochara*, our material is also similar to *S. subglobosa* (GROVES, 1926) HORN AF RANTZIEN, 1959 in size and shape but differs in the ornamentation, which is much heavier in this species. The most significant characters for distinguishing these *Sphaerochara* species from each other appear to be related with the ornamentation. From extant charophytes it is known that the degrees of calcification and ornamentation

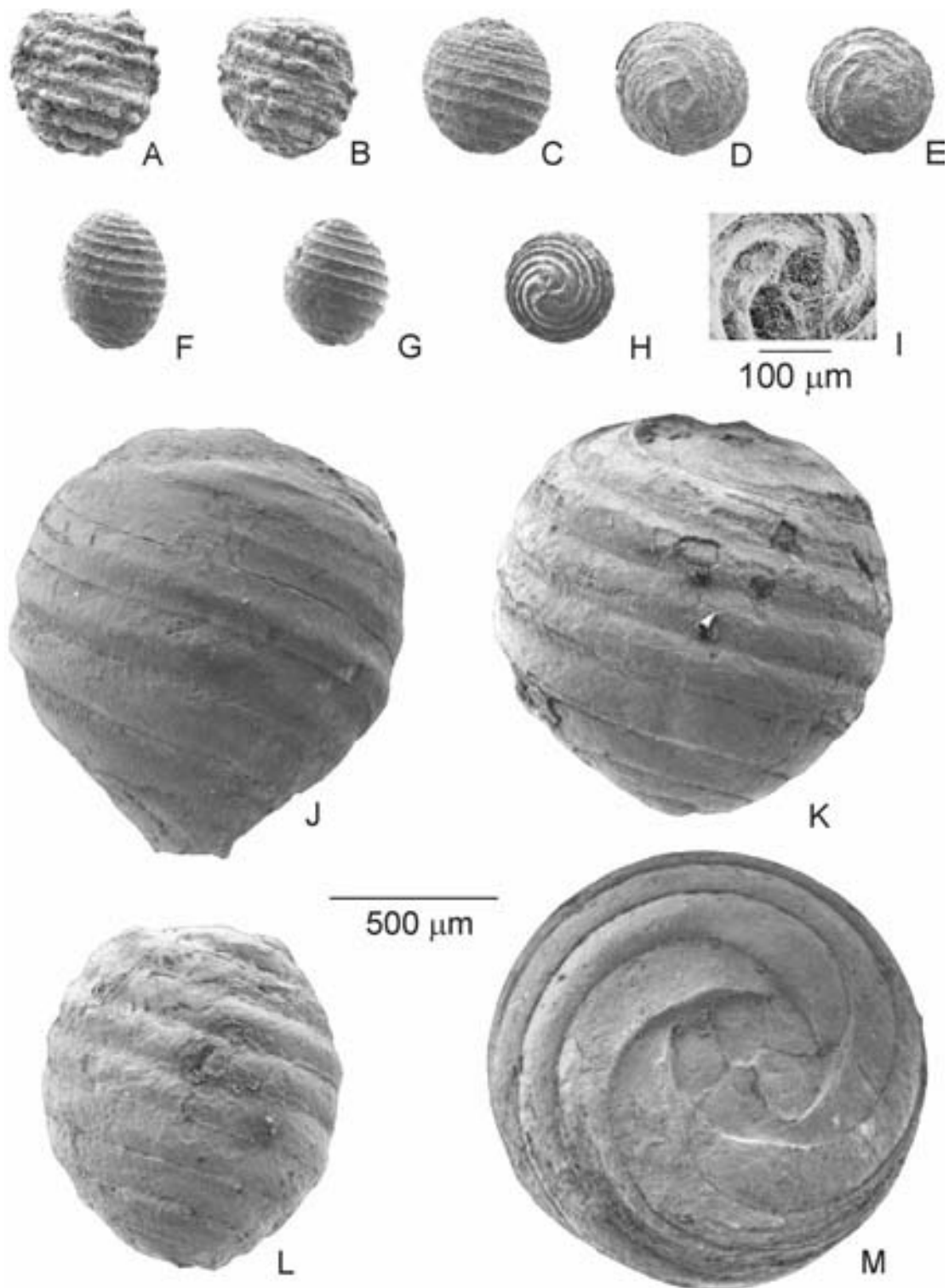


FIGURE 9 | Gyrogonites of genera *Sphaerochara* and *Raskyella*. A to E) *Sphaerochara hirmeri*, sample O1.0.45, A to C) lateral views, D) base, E) apex. F to I) *Sphaerochara inconspicua*, sample 14.1.07, F and G) lateral views, H) apex, I) base. J to M) *Raskyella peckii meridionale*, sample PP.54, J to L) lateral views, M) apex.

are strongly controlled by the alkalinity of water rather than by the plant itself, which casts doubt on whether the presence of nodules in two-thirds of the population is significant or not for taxonomic purposes.

Since a taxonomic revision of the Palaeogene *Sphaerochara* is beyond the scope of our study, we place the material studied in the most similar species, which is *Sphaerochara hirmeri*.

***Sphaerochara inconspicua*** (BRAUN ex UNGER, 1850)  
FEIST-CASTEL, 1977  
Figures 9F to 9I

- 1850 *Chara inconspicua*, Alex Braun manuscript in Unger, p. 34.  
1855 *Chara inconspicua* A. Br., Heer, p. 26, pl. 4, figs. 7a-7d.  
1927 *Gyrogonites inconspicuus*, Pia, p. 90.  
1955 *Tolypella inconspicua* (Al. Braun) nov. comb., Mäddler, p. 307, pl. 26, figs. 44-45.  
1959 *Charites inconspicua* (Unger, 1850) nov. comb., Horn af Rantzien, p. 66, pl. 5, figs. 1-4.  
1977b *Sphaerochara inconspicua* (Al. Braun ex Unger) n. comb., Feist-Castel, p. 121, pl. 5, figs. 1-4.  
1983 *Sphaerochara inconspicua* (Unger) Feist Castel, 1977, Berger, p. 14, fig. 3, num. 16; pl. 2, fig. 8.  
1986 *Sphaerochara* cf. *inconspicua* (A. Braun ex Unger) Feist-Castel, Riveline, p. 78, pl. 36, figs. 3-7.

**Material:** Twelve gyrogonites from samples 14.1.07 and 14.1.08 from Es Macar de sa Llosa (Menorca).

**Description:** Gyrogonites are medium-sized, with height ranging from 385-480 µm (often 435-460 µm) and width from 313-385 µm (often 335-380 µm). Shape ovoidal to ellipsoidal with an isopolarity index (ISI) ranging from 115 to 150 (often 125-130). Apex rounded and without modifications. Base rounded to slightly truncated. Basal plate visible from outside. Spiral cells concave, with 10-12 convolutions in lateral view and 50 µm of maximum width. Cell sutures prominent.

**Discussion:** Most species of *Sphaerochara* bear sub-spheroidal gyrogonites, with an ISI rarely exceeding 115. *S. inconspicua* was also described originally as bearing globular gyrogonites, but the same name was used later for more ellipsoidal gyrogonites bearing a large number of convolutions. Riveline (1986) appears to be the only author to employ the original definition. The gyrogonites from Menorca are most similar to the population described by Feist-Castel (1977b), to which we refer for comparative purposes. The present taxonomic attribution is probably equivalent to *Charites inconspicua* and *Maedlerisphaera ulmensis* in this locality, reported by Bourouilh (1973). These species are now placed in genus *Sphaerochara*.

#### ***Sphaerochara* sp.**

**Material:** Two gyrogonites in sample 13.1-1 from borehole 13.1 (Alaró, Mallorca).

**Description:** Gyrogonites ranging 375-385 µm high and 360 µm wide, with a sub-spheroidal shape (ISI 103-106). Apex rounded without modification. Base rounded

showing a large basal plate visible from the outside. Spiral cells 60 µm wide, showing 9 convolutions in lateral view. Ornamentation of one gyrogonite made of well-developed prominent tubercles, reaching the apex. The other gyrogonite shows a central crest following the spiral cells.

**Discussion:** The small number of specimens does not permit greater taxonomic precision.

**Family:** Raskyellaceae GRAMBAST, 1957

GENUS ***Raskyella*** L. et N. GRAMBAST, 1954  
***Raskyella peckii*** subsp. ***meridionale*** GRAMBAST, 1960  
Figures 9J to 9M

- 1954 *Raskyella peckii* nov. sp., L. and N. Grambast, p. 669, fig. 1.  
1957 *Raskyella peckii* Grambast, Grambast, pl. 5, figs. 7-9.  
1960 *Raskyella pecki* subsp. *meridionale* n. ssp., Grambast, pp. 192-194, text-fig. 1, pl. 1, figs. e-i, pl.2: figs. 1-7.

**Material:** About 400 gyrogonites from samples 01.0.10 and PP.54 from Santa Ponça-Peguera (Mallorca).

**Description:** Gyrogonites very large, 1110-1375 µm high (mean value 1237 µm) and 945-1375 µm wide (mean value 1189 µm). Normally pear-shaped but sub-spheroidal or ellipsoidal specimens occur as well. Isopolarity index ranges from 93 to 117, with a mean value of 104. Apex flattened, formed by an apical operculum of five triangular to pentagonal cells. Base rounded or elongated. Basal pore pentagonal, 55-243 µm (mean 143 µm) in diameter and generally located inside a funnel. Seven to ten convolutions are visible laterally. Spiral cells are 135-216 µm in width. They are flat or slightly convex but become concave near the base. Also, they become shorter around the operculum but do not show further apical modification.

**Discussion:** The sub-species *meridionale* is clearly larger and more globular than the nominal sub-species, which shows usually a height of 900-1100 µm and a width of 900-1075 µm. Previously, the subspecies *meridionale* was only known from particular Saharan localities (Grambast, 1960; Mebrouk et al., 1997), which means that the Balearic population is its northernmost occurrence. Up to now the precise ecological conditions leading to the appearance of the two subspecies have not been clarified. Temperature of lake water is perhaps one reason for their separate occurrence and different size ranges. Other causes may be related to the depositional environment. Thus, in the South-Pyrenean basin we found *R. peckii* subsp. *peckii* in thin calcareous layers attributed to ephemeral lakes with abundant siliciclastic inputs (Martín-Closas et al., 1999), whereas in Mallorca *R. peckii meridionale* occurs in thick

TABLE 2 | Summary of biostratigraphic implications of the present study for the dating of non-marine formations of the Balearic Palaeocene. Biozones from Riveline et al. (1996) modified by Martín-Closas et al. (1999).

AGE		BIOZONES	BALEARIC CHAROPHYTE ASSEMBLAGES	LOCATION
Miocene	Aquitanian	N. (T) GINSBURGI	<i>Lychnothamnus langeri</i> <i>Nitellopsis</i> sp.	Cala Blanca Fm. (Sineu)
		S. BERDOTENSIS		
		R. NITIDA		
Oligocene	Chattian	C. NOTATA	<i>Lychnothamnus praelangeri</i> <i>Sphaerochara hirmeri</i>	Cala Blanca Formation (Sta. Ponça-Peguera)
		S. UNGERI		
		C. MICROCERA		
	Rupelian	R. MAJOR	GAP	
		S. PINGUIS	<i>Lychnothamnus stockmansii</i> <i>Sphaerochara inconspicua</i>	Cala Blanca Formation (Menorca)
Eocene	Priabonian	S. VECTENSIS	<i>H. vasiformis-tuberculata</i> <i>Nitellopsis (T.) oemula</i>	Peguera Fm. (Alaró)
		H. VASIFORMIS-TUBERCULATA		
		G. TUBEROSA		
		P. REPANDA		
	Bartonian	R. VADASZI	GAP	
		C. FRITELI	<i>Raskyella peckii meridionale</i> <i>Maedleriella mangeloti</i> <i>Maedleriella serialis</i> <i>Harrisichara caeciliana</i> <i>Gyrogonia</i> sp. 1	Peguera Formation (SW Mallorca)
	R. PECKII			
	Lutetian			

successions of lacustrine marls and limestones attributed to long-lasting, highly alkaline lakes. Stability of the water table was a leading factor in the growth of large *Lamprothamnium papulosum* gyrogonites in brackish lakes in southern France (Soulié-Märsche, 1989, p. 150).

## BIOSTRATIGRAPHY

The biostratigraphic results of our study are summarised in Table 2. The Peguera Limestone Fm includes

two different biostratigraphic assemblages. The first is found in SW Mallorca and includes *Raskyella peckii* subsp. *meridionale*, *Maedleriella mangeloti*, *Maedleriella serialis*, *Harrisichara caeciliana* and *Gyrogonia* sp. 1 in Santa Ponça – Peguera, whereas in Cala d'Egos and in Cala Blanca only a part of this association was found. These charophytes belong to the *Raskyella peckii* Zone of Riveline et al. (1996), modified by Martín-Closas et al. (1999). However, in the absence of *Chara friteli* and associated taxa, which mark the upper limit of this biozone, the assemblage has to be dated with the total range of



*Raskyella peckii*. This species ranges from the Early Lutetian to the Late Bartonian (Martín-Closas et al., 1999), including *de facto* the range of the *Raskyella peckii* and *Chara friteli* biozones (Table 2). The second charophyte assemblage of the Peguera Fm. was found in borehole samples from Alaró. The assemblage is formed by *Harrisichara vasiformis-tuberculata*, *Nitellopsis (Tectochara) aemula* and *Sphaerochara* sp. in borehole 13.1, whereas only *Gyrogona* sp. 2 occurs in borehole S.1. The assemblage of borehole 13.1 belongs to the *Harrisichara vasiformis-tuberculata* Zone of Riveline et al. (1996), which is Middle Priabonian in age according to correlations with the mammal biozone MP18 and the nannoplankton biozone NP 19-20 in southern England. The charophytes of borehole S.1 are of little biostratigraphic interest. These findings show that the whole chronostratigraphic range of the Peguera Fm is Middle and Upper Eocene. Also, according to our results, the deposition of the Peguera Formation began later in central Mallorca (Alaró) than in the SW of the island (Santa-Ponça-Peguera). A chronostratigraphic gap comprising three biozones at the Bartonian-Priabonian boundary, exists between the charophyte assemblages found near the base of the formation in the two areas (Table 2).

The Cala Blanca Fm has three different biostratigraphic assemblages. The oldest assemblage was found in Es Macar de Sa Llosa, Menorca, and yields the association of *Sphaerochara inconspicua* and *Lychnothamnus stockmansii*. The latter species occurs in the *Stephanochara vectensis* and *Stephanochara pinguis* Zones, which comprise the Late Priabonian to Early Rupelian time interval (Riveline et al., 1996). However, if the use of *Sphaerochara inconspicua* is admitted in biostratigraphy in spite of its confusing definition, the overlay of both species limits this age to the Early Rupelian, i.e. to the *Stephanochara pinguis* zone (Riveline, 1986). The second assemblage occurs in samples from Santa Ponça-Peguera (Mallorca) and is formed by *Lychnothamnus praelangeri* and *Sphaerochara hirmeri*. This assemblage is included in the Zones *Chara microcera*, *Stephanochara ungeri* and *Chara notata* by Riveline et al. (1996). If we take into account the total chronologic range of *R. praelangeri*, the association is Late Rupelian (=Late Stambian) to Chattian in age. According to these results, a biostratigraphic gap exists between the first charophyte associations found in Menorca and those in Mallorca, which comprise the *Rhabdochara major* Zone (Middle Ruppelian). The third assemblage is formed by *R. langeri* and *Nitellopsis* sp. It was found in core samples from borehole 9.1. near Sineu, Mallorca. The first species is present in a number of biozones from Riveline (1986) and Riveline et al. (1996): i.e. *Chara notata* Zone, *Rantzieniella nitida* Zone and *Stephanochara berdotosensis* Zone. The total range of *R. langeri* is thus Late Chattian to Early Burdigalian.

## DISCUSSION AND CONCLUSIONS

Fifteen different charophyte taxa have been found and described in the Palaeogene of Mallorca and Menorca and belong to genera *Maedleriella*, *Harrisichara*, *Nitellopsis*, *Gyrogona*, *Lychnothamnus*, *Sphaerochara* and *Raskyella* (Table 1). This flora enables us to characterise biostratigraphically the Palaeogene, non-marine formations of the Balearic Islands (Table 2). The Peguera Fm in Mallorca contains *Raskyella peckii* subsp. *meridionale*, *Harrisichara caeciliana*, *H. vasiformis – tuberculata*, *Maedleriella mangeloti*, *M. serialis* and *Nitellopsis (Tectochara) aemula*. The Cala Blanca Fm gives *Lychnothamnus langeri*, *L. praelangeri* and *Sphaerochara hirmeri* in Mallorca, and *Lychnothamnus stockmansii* and *Sphaerochara inconspicua* in Menorca. Our results indicate that Peguera Fm deposited from the Lutetian to the Middle Priabonian, whereas Cala Blanca Fm. developed during the Late Priabonian and Oligocene. A significant diachronism exists between the beginning of non-marine deposition in southwestern and central Mallorca.

The correlation of the non-marine deposits with the marine formations of Mallorca proposed by Ramos-Guerrero et al. (1989) was only possible biostratigraphically and by sequence stratigraphic criteria. Lithostratigraphic correlation between the two domains is difficult due to the orogenic structuring of the Balearic Palaeogene dur-

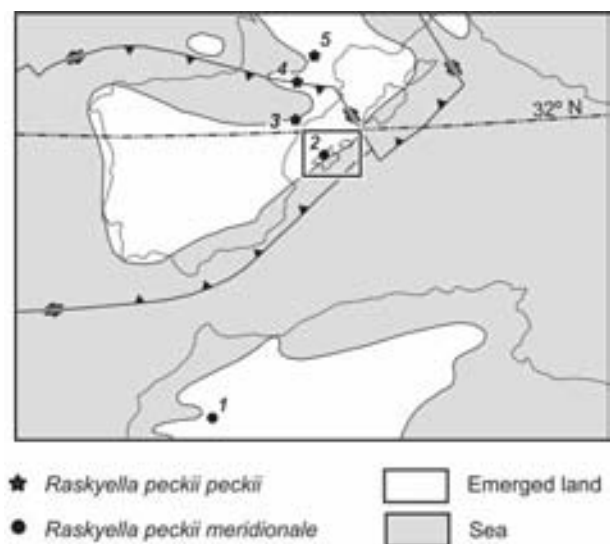


FIGURE 10 | Biogeography of *Raskyella peckii meridionale* (dots) and *R. peckii peckii* (asterisks). The presence of the first subspecies in Mallorca (square) marks its northernmost occurrence (map modified from Ramos et al., 2001).

Legend of localities: 1: Glib Zegdou and Gour Lezib, Algeria (Mebruk et al., 1997); 2: Santa Ponça-Peguera, Mallorca, Spain (this study); 3: Pontils, Les Colomines and Santa Maria de Miralles, Catalonia, Spain (Anadón and Feist, 1981); 4: Sant Jaume de Frontanyà, Catalonia, Spain (Martín-Closas et al., 1999); 5: Hauterive near Castres, Languedoc, France (Soulié-Märsche, 1971).

ing Miocene times. The south-eastern marine deposits, which may be laterally equivalent to the Peguera Limestone Formation, include foraminifera ranging from the Upper Lutetian to Bartonian, while the marine equivalents of the Cala Blanca Detrital Formation include foraminifera of the Priabonian to Lowermost Rupelian (Ramos-Guerrero et al., 1989).

In terms of biogeography, the Eocene charophytes of Mallorca show affinity with North-African flora. This is seen in the presence of *Raskyella peckii meridionale* in Mallorca, which is the only European record of this Algerian subspecies. The palaeogeographic position of Mallorca during the Eocene was adjacent to the south-eastern Iberian Plate (Ramos et al., 2001), which means that the boundary between the subspecies *meridionale* and *peckii* did not coincide with a palaeogeographic marine barrier, as previously thought, but corresponded rather to the 32° N parallel within the Iberian Plate (Fig. 10). The size differences between the gyrogonites of these subspecies suggest, through comparison with living characeans, that this boundary may be related to lake water palaeotemperatures.

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