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# Early Cretaceous charophytes from south Dobrogea (Romania). Biostratigraphy and palaeobiogeography

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## ABSTRACT

Eleven boreholes and one outcrop of the Lower Cretaceous in South Dobrogea (south-eastern Romania) were sampled for charophytes. Twenty species are described and illustrated in two non-marine rock units, the Zăvoaia Member and the Gherghina Formation. The Zăvoaia Member contains a charophyte assemblage dominated by *Feistiella bijuescensis*, aff. *Mesochara harrisii*, *Nodosoclavator bradleyi*, *Clavator bilateralis*, and *Clavator grovesii* var. *grovesii*, indicating a Berriasian age. Other less abundant species include *Feistiella* sp., *Latochara* sp., *Mesochara dobrogeica* sp. nov., *Globator maillardii* var. *nurrensis*, *Atopochara trivolvis* var. *micrandra*, *Clavator grovesii* var. *discordis*, *Hemiclavator adnatus*, and *Hemiclavator neimongolensis* var. *posticecaptus*. The occurrence of *G. maillardii* var. *nurrensis* in this assemblage suggests late Berriasian age. The Gherghina Formation is dominated by the species *Atopochara trivolvis* var. *triquetra* and *Clavator grovesii* var. *jiuquanensis*. Other less abundant species include *Sphaerochara andersonii*, aff. *Mesochara harrisii*, *Globator maillardii* var. *trochiliscoides*, *Globator maillardii* var. *biutricularis*, *Clavator harrisii* var. *reyi*, and *Clavator ampullaceus* var. *latibracteatus* var. nov. This assemblage indicates a late Barremian–early Aptian age. This study sheds new light on the palaeobiogeographical distribution of Lower Cretaceous charophytes in the Tethyan realm. Well-known western European charophyte species such as *F. bijuescensis*, *S. andersonii*, *G. maillardii* var. *trochiliscoides*, *H. adnatus*, and *H. neimongolensis* var. *posticecaptus* are herein described for the first time in eastern Europe. Very significantly, this is the first report in Europe of the hitherto North American taxon *C. bilateralis*, while the species *C. ampullaceus* has previously been reported only from the Middle East and eastern Africa.

## 1. Introduction

Charophyte fructifications (gyrogonites and utricles) have been extensively reported worldwide in non-marine sedimentary rocks as old as Silurian in age (Feist et al., 2005). Fossil charophytes have mainly been used as biostratigraphic markers of non-marine deposits and as palaeoenvironmental proxies of ancient freshwater and brackish-water aquatic systems. Palaeontological works based on Cretaceous charophytes are relatively scarce in Romania and in the entire eastern European area. Previous studies based on Cretaceous charophytes from South Dobrogea have been performed by Neagu and Georgescu-Donos (1973), who recovered an assemblage of five species including *Atopochara trivolvis* var. *trivolvis*, *Clavator grovesii* var. *jiuquanensis* (synonym: *Clypeator europaeus*), *Hemiclavator neimongolensis* (reported as *Clavator thorali*), and *Clavator* sp. from marly limestone located in a cliff near the village of Peştera (Medgidia, South Dobrogea). These authors provided a relative age of uppermost Barremian–lower Aptian for the studied deposits. Avram et al. (1993) developed a comprehensive biostratigraphic analysis of 20 drilling boreholes in South Dobrogea. These authors provided the relative age of several marine and

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non-marine units, based on foraminifera, ammonites, ostracods, palynomorphs, and charophytes. Furthermore, they dated two rock units, the marine Ramadan Formation and the terrestrial Gherghina Formation, as upper Barremian–lower Aptian and middle–upper Aptian, respectively. Continental and transitional deposits of South Dobrogea were later studied by Stoica (2007), using non-marine ostracods. This author made a detailed study of 25 hydrogeological boreholes that had been dug more than 50 years ago during the construction of the Danube-Black Sea Canal. Stoica (2007) reported a diverse and well-preserved assemblage composed of forty-seven species of freshwater to brackish-water ostracods, including seven new species. This ostracod assemblage was integrated by Stoica (1997; 2007; 2013) into the first two ostracod zones of Anderson (1985), defined in the Purbeck and Wealden beds of southern England, i.e., Cypridea dunkeri and Cypridea granulosa zones, or the first two subzones of Theriosynoecum forbesi Zone in the revised zonation performed by Horne (1995). This integration proves the presence of lower Purbeck and the first part of middle Purbeck in the investigated sediments, indicating that the ostracod fauna from the Zăvoaia Member is Berriasian in age. Despite Stoica (2007) having reported the presence of charophytes associated with this Purbeckian ostracod fauna, the charophyte flora has never been studied in detail.

In the neighbouring Pre-Dobrogean Basin (south-western Ukraine and easternmost Moldova), charophytes were studied by Shaikin (1976) from several oil and gas drilling boreholes. This author identified thirty species and defined four biostratigraphic zones in deposits ranging in age from Middle Jurassic to Lower Cretaceous (Barremian). However, neither proper illustrations nor detailed descriptions were provided by this author. Shaikin et al. (1992) attempted to establish a charophyte correlation between the Pre-Dobrogean Basin, the Crimean plain (Ukraine) and the North Caspian depression (Russia and Kazakhstan), on the basis of private data compiled by oil companies. They highlighted the potential of charophytes in biostratigraphic correlations between distant basins. However, in the last three decades, no significant studies based on Mesozoic charophytes have been published concerning the South Dobrogea and Pre-Dobrogean basins.

The present study illustrates and describes in detail the Lower Cretaceous charophyte flora from South Dobrogea (south-eastern Romania), providing the relative age of the two lithological units, the Zăvoaia Member (upper part of the Amara Formation) and the Gherghina Formation. These results are compared with those obtained by the study of ostracods from the same boreholes. Moreover, this study analyses the palaeobiogeographic distribution of this flora since several species are reported for the first time in the eastern part of the Tethyan Cretaceous Archipelago.

## 2. Materials and methods

Fossil charophytes were extracted from 45 soft rock samples, initially prepared for ostracods (marly limestone and clays), from 11 drilling cores and one outcrop, in seven localities of South Dobrogea, i.e., Dunărea, Poarta Albă, Saligny, Nazarcea, Ilie Barza, Cernavodă and Fetesti Baltă (Fig. 1). About 300 g of sediment per sample were extracted from the drilling cores. About 2 kg of sediment was recovered from the single outcrop sample in Cernavodă. Sediments were disaggregated and sieved using sieves with mesh apertures ranging from 0.063 mm to 0.125 mm. Microfossils were then picked out by hand using a light microscope Zeiss Stemi SV 11 housed at the Geology Department of the University of Bucharest (Romania). Selected fossil charophytes were cleaned with an ultrasound machine and measured using the Motic Images Plus 2.0 software with a Motic BA310 stereomicroscope housed at the Department of Earth and Ocean Dynamics of the University of Barcelona, Spain (*Departament de Dinàmica de la Terra i de l'Oceà, Facultat de Ciències de la Terra, Universitat de Barcelona*). Finally, representative specimens were photographed using a Quanta 200 scanning electronic microscope (SEM) housed in the Scientific and Technological Centres of the University of Barcelona, Spain (CCiT-UB). The material studied and illustrated herein, and the holotypes/para-types extracted from South Dobrogea are housed in the Laboratory of Palaeontology of the University of Bucharest (LPB). The collection enumeration ranges from LPB_IV_CH 101 to LPB_IV_CH 172.

## 3. Geological and stratigraphic setting

The region of South Dobrogea represents an elevated sector of the Moesian Platform that lies in south-eastern Romania between the lower course of the Danube and the Black Sea coast. The Moesian Platform is a Precambrian block incorporated in the epi-Hercynian European Platforms (Săndulescu, 1984). The Dobrogean sector of the Moesian Platform is divided by the Capidava-Ovidiu Fault into two tectonic compartments, Central Dobrogea and South Dobrogea (Fig. 1).

The South Dobrogea basement has been identified in a few boreholes located near Palazu and Cocosu, below the depth of 500 m (Visarion et al., 1988; Ionesi, 1994). The basement consists of Archaic gneisses (Ovidiu series), Lower Proterozoic high-grade metamorphic rocks (Palazu series) and Upper Proterozoic (Vendian) volcano-sedimentary rocks (Cocosu Formation). Several relative ages were inferred from the covering sedimentary sequences in South Dobrogea, i.e., Cambrian?–Carboniferous, Permian?–Triassic, Middle Jurassic–Upper Cretaceous, Eocene–Oligocene, and Miocene–Pliocene. These sedimentary cycles are separated by stratigraphic gaps of different time spans (Băncilă, 1973; Tătărîm et al., 1977; Avram et al., 1988, 1993; Dragastan et al., 1998). The spatial distribution of these sedimentary sequences is not uniform in South Dobrogea and they are influenced by the regional palaeogeography and tectonics.

Several Upper Jurassic–Lower Cretaceous lithostratigraphic units have been defined in South Dobrogea (Cernavodă area), based on surface and subsurface data obtained over decades of intense research (Fig. 2). The oldest deposits intercepted in boreholes are represented by the Rasova Formation which is composed of a 600-m-thick carbonate sequence (limestone and dolomite), Oxfordian–Tithonian in age (Dragastan, 1985; Dragastan et al., 1998). The Rasova Formation is covered by a thick marine and continental sequence termed the Amara Formation (Dragastan, 1985). This unit is divided into two members with different lithologies, namely Cireşu and Zăvoaia. The Cireşu Member consists of intervals of evaporites (gypsum, anhydrite, and gypsiferous clays) that are up to 200-m-thick. This lithological unit was first recognised by Băncilă (1973) and displays a wide extension in South Dobrogea and in the eastern Romanian Plain. The Cireşu Member represents the base of the Purbeckian facies and is late Tithonian in age. The Zăvoaia Member is divided into two characteristic Lower Cretaceous intervals. The first interval is composed of a 60-m-thick carbonate succession (bioclastic limestones, marlstones, and oolites), rich in early Berriasian marine macro- and microfauna, representing a marine intercalation within the Purbeckian Amara Formation (Stoica, 2007). This carbonate sequence is overlaid by another 60-m-thick sequence of variegated clays, marls, marly limestones, calcarenites, calcareous sandstones, oolitic limestones, and clayey sandstones. This unit has previously been reported by Băncilă (1973) as the "poly-coloured clay complex". Dragastan (1985) included it in the Zăvoaia Member of the Amara Formation. The ostracod fauna extracted from the Zăvoaia Member allowed correlation with the Purbeckian ostracod zonation of

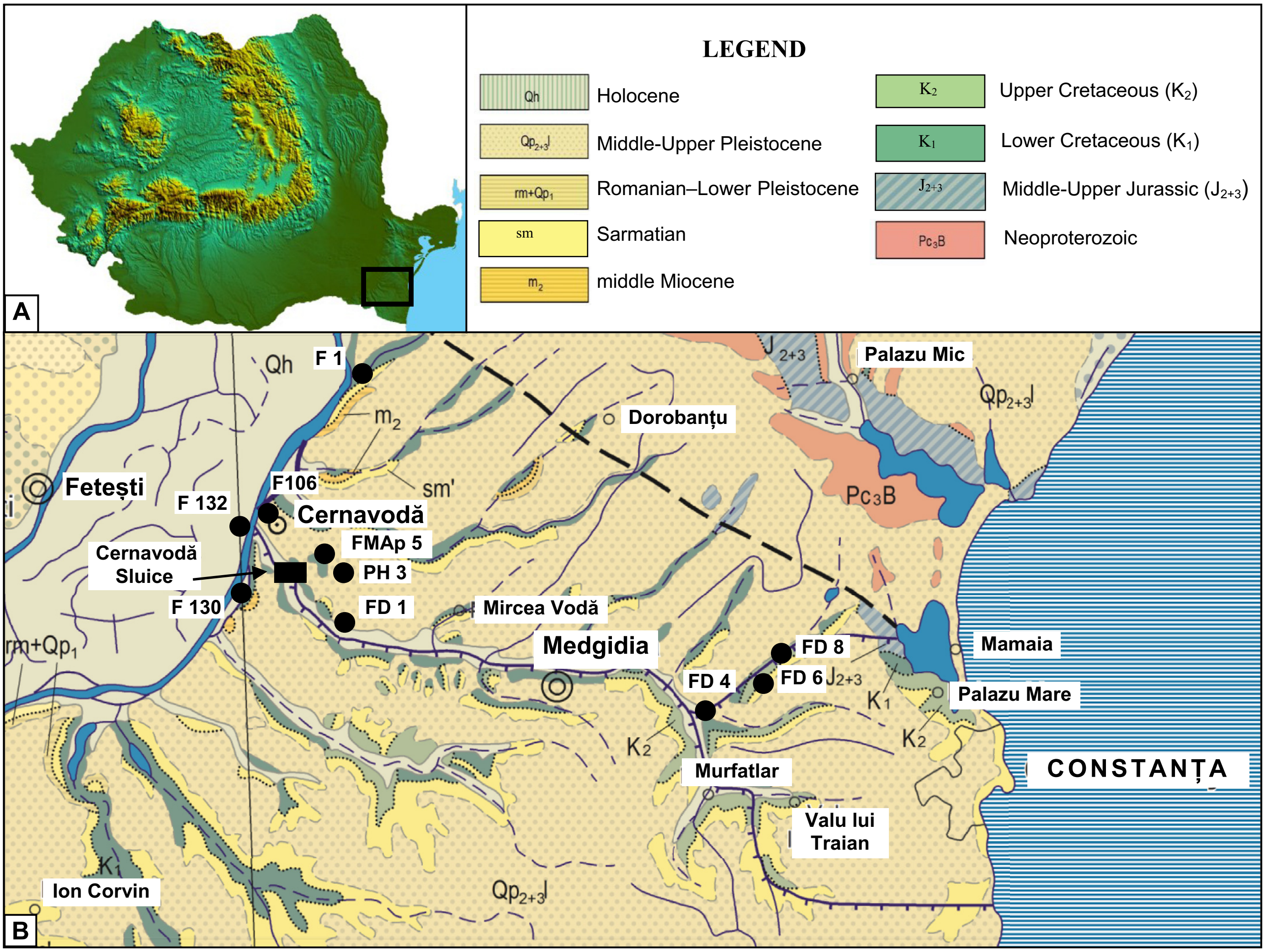


**Fig. 1.** Geographic and geological settings of the study area. **A**. Outline of Romanian geography showing the studied area (black square). **B**. Geological map of the studied area showing the location of the 11 drilled boreholes and the outcrop sampled (modified from Dragastan et al., 2014).

Horne (1995). Stoica (2007) identified the two lower ostracod zones, Cyprideа dunkeri and Cypridea granulosa, suggesting that the upper part of the Zăvoaia Member is Berriasian in age. Rocks attributed to the Zăvoaia Member are not exposed in South Dobrogea, but are located close to the surface, being encountered in wells as deep as 50-m to 90-m. The Zăvoaia Member was occasionally intercepted during excavation works to build the foundations of the new railway bridge over the Danube and the Danube-Black Sea Canal. Most of the charophyte species described in this study have been extracted from marls and clays located at the 2nd interval of the Zăvoaia Member (Fig. 2). This charophyte-rich member is covered by a 40-m-thick carbonate marine sequence termed the Cernavodă Formation which includes the Hinog and Alimanu members. This formation crops out in several locations in South Dobrogea and it has been studied in detail on the right bank of the Danube River, upstream of the Cernavodă bridge. The diverse and rich fossil content extracted from this marine unit (shallow marine macro- and microfauna) indicates a late Berriasian–Valanginian age (Neagu et al., 1977; Neagu and Dragastan, 1984; Avram et al., 1995; Neagu et al., 1997; Dragastan et al., 1998, 2014). The Cernavodă Formation is discordantly overlaid by the Barremian–Aptian fluvio-lacustrine deposits of the Gherghina Formation. Fluvial facies are composed of fine to medium clast-supported conglomerate beds with reddish clay matrix alternated with whitish sandstone and kaolinitic claystone intervals. Lacustrine deposits are represented by yellow claystone beds, up to 0.5-m-thick, that are rich in Wealdian microfossils (freshwater ostracods and charophyte fructifications). Part of the charophyte species described here was recovered from this lacustrine interval of the Gherghina Formation. The fluvio-lacustrine facies of the Gherghina Formation changes vertically and laterally towards the marine marlstones and fine sandstones of the Ramadan Formation (Fig. 2). This rock unit provided abundant marine fauna such as ostreid bivalves, ostracods and foraminifera (mainly orbitolinids).

The studied charophyte assemblage was extracted from several hydrogeological/hydrotechnical cores along the Carasu Valley (F1 Dunărea, F132 Cernavodă Pod, FD1 Saligny, FD Poarta Albă, FD6, and 8 Nazarcea) that were dug between the years 1958 and 1968 in South Dobrogea (Fig. 1). Most of these cores were first described by Băncilă (1973). They are up to 300-m-deep, intercepting several lithological units, as previously mentioned, i.e., Upper Jurassic limestones and dolomites of the Rasova Formation, uppermost Jurassic evaporites of the Cireşu Member, Berriasian marine and Purbeckian sediments of the Zăvoaia Member, upper Berriasian–Valanginian marine carbonates of the Cernavodă Formation, and Barremian/Aptian continental and marine deposits of the

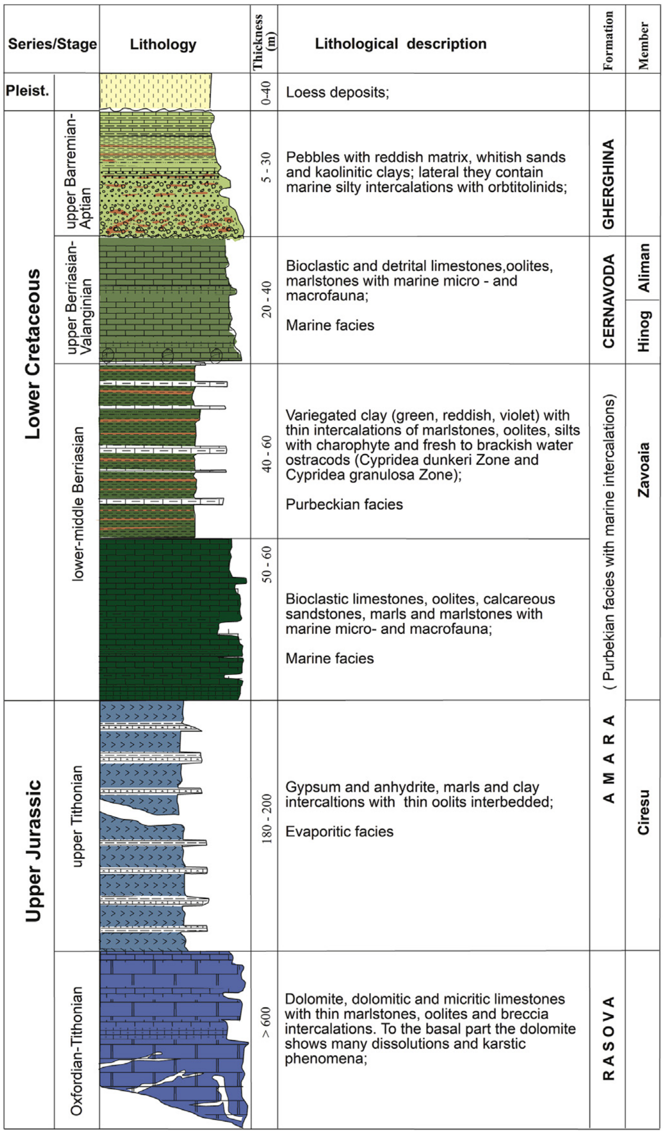


**Fig. 2.** General stratigraphic log near the locality of Cernavodă, showing the complete sedimentary sequence (modified from Stoica, 2007).

Gherghina and Ramadan formations (Figs 2 and 3). Two new shallow hydrogeological boreholes, PH3, and FMBAp5, have also been considered in this study. Both boreholes were dug close to Cernavodă village, intercepting mainly the subsurface Gherghina and Ramadan formations (Figs 1 and 3).

## 4. Systematic palaeobotany

Twenty charophyte species have been identified, described, and illustrated from the variegated interval of the Zăvoaia Member (Amara Formation) and the Gherghina Formation in South Dobrogea (south-eastern Romania).
Family ‘Porocharaceae’ Grambast, 1962

Genus *Feistiella* Schudack, 1986
***Feistiella bijuescensis*** Schudack, 1986
Fig. 4A–E

*Material.* Several well-preserved gyrogonites were recovered from 14 samples in drill cores F1, F6, F8, F106, and F130 (Table 1). Twenty-two gyrogonites from the sample Nazarcea F6/113 were measured.
*Description.* Gyrogonites are large, 681–892 μm high (mean 802 μm) and 487–709 μm wide (mean 645 μm), vase-shaped, prolate-spheroidal to subprolate, according to the gyrogonite terminology of Horn af Rantzien (1959) and Feist et al. (2005), with an isopolarity index (ISI) ranging between 119 and 140 (mean 126). The gyrogonite's maximum width is located just below the equator. The apex is slightly tapering and truncated. It displays a large rose-shaped apical pore measuring 130 μm in diameter (Fig. 4A) with the spiral cells reaching its rim and turning inside the pore. The base is rounded or slightly tapering. Spiral cells are concave, 85 μm wide, and separated by protruding narrow intercellular ridges (Fig. 4B and C). Laterally, 10 to 12 (commonly 11) convolutions are visible (Fig. 4B and C). Basal pore is small and pentagonal in shape, 81 μm in diameter (Fig. 4D). An undivided pentagonal, slightly rounded basal plate, 100 μm in diameter, can be observed from the inside of the gyrogonite (Fig. 4E).
*Remarks. F. bijuescensis* shares morphometric parameters with the species *Porochara jargorensis* Shaikin et Saidakovsky, 1976 in Shaikin (1976) or *Porochara jaccardi* (Heer, 1865) Mojon, 1989, as reported in Lower Cretaceous deposits from the Pre-Dobrogean Basin by Shaikin (1976) and from the South Dobrogea Basin by Avram et al. (1993), respectively. However, description and illustrations of these taxa in the aforementioned publications do not provide any information about the basal plate, which is the key parameter distinguishing genus *Feistiella*. In the future, a revision of the Shaikin and Avram collections should be performed in order to check that the species reported by these authors really are equivalent to *F. bijuescensis*. This species clearly differs from the Upper Cretaceous *F. malladae*, which is considerably larger (200 μm) and displays a more rounded shape and a lower number of convolutions than *F. bijuescensis*.
*Distribution. F. bijuescensis* was first reported and described by Schudack (1986) from the upper Berriasian of Bijuesca, Iberian Chain (Aragón, Spain). Herewith we provide the first record of *F. bijuescensis* outside its type locality.
*Age.* Late Berriasian (Schudack, 1986).

***Feistiella* sp.**
Fig. 4F–H

*Material.* A small number of gyrogonites were recovered from two samples in the drill boreholes F1 and F31 (Table 1). Three specimens were measured from the sample Saligny F1/74–75.5.
*Description.* Gyrogonites are small, 600 μm high and 485 μm wide on average, showing a prolate-spheroidal shape with an ISI of 127 (Fig. 4G). The gyrogonite's maximum width occurs in the equator. The apex is truncated, showing a large rose-shaped apical pore of 130 μm in diameter (Fig. 4F). The base is rounded, showing a small pentagonal basal pore (Fig. 4H). Nine concave spiral turns can be observed in the lateral view. Spiral cells are 127 μm wide and are separated by narrow intercellular ridges. A pentagonal, rounded and undivided basal plate can be observed inside the gyrogonite.
*Remarks.* This species displays similar morphological parameters to *F. bijuescensis*. However, the gyrogonites are clearly smaller in size (ca. 200 μm in height), showing fewer spiral turns when observed laterally. The lower number of specimens recovered hinders a more detailed determination.
*Distribution.* This study represents the first report of this species.
*Age.* Berriasian, based on the associated charophyte and ostracod assemblages.

Genus *Latochara* Mädler, 1955 emend. Feist et Cubaynes, 1984
***Latochara* sp.**
Fig. 4I

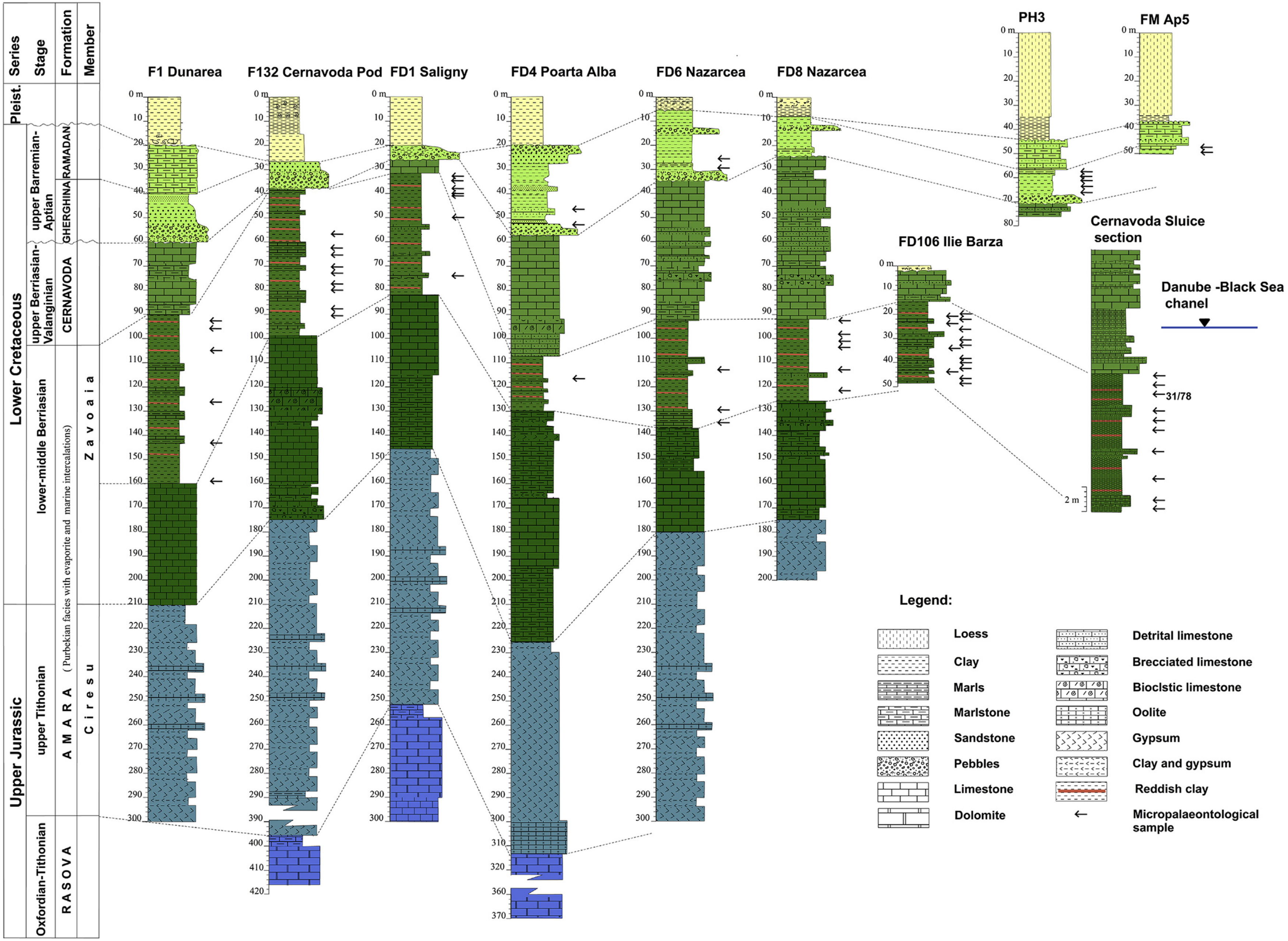


**Fig. 3.** Synthetic stratigraphic logs for the main boreholes near the localities of Dunărea, Poarta Albă, Saligny, Nazarcea, Ilie Barza, Cernavodă, and Fetesti Baltă in South Dobrogea (south-eastern Romania), showing their correlation and facies associations. Arrows represent the stratigraphic positions of samples bearing charophytes (modified from Stoica, 2007).

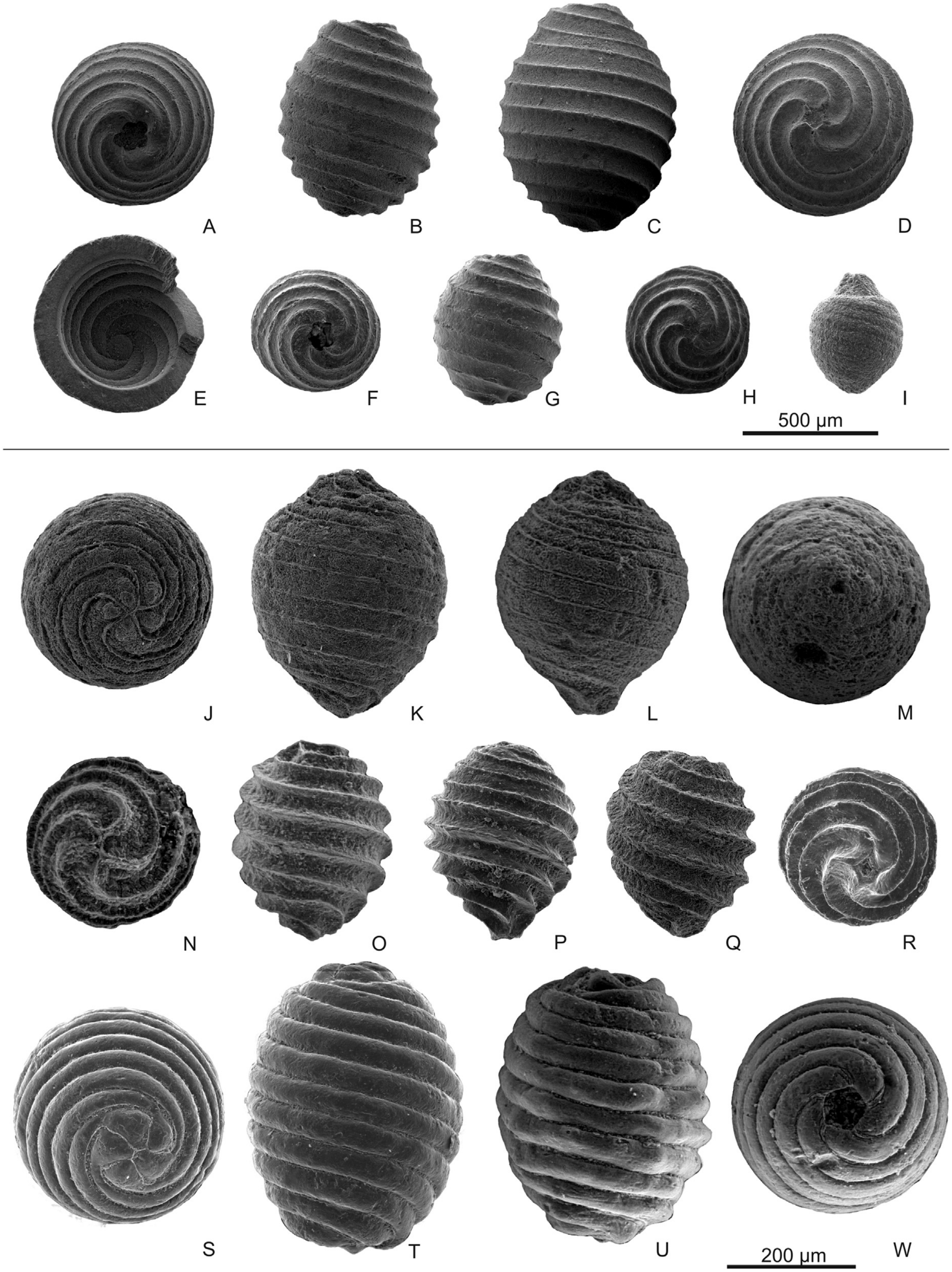


**Fig. 4.** Gyrogonites from South Dobrogea (south-eastern Romania). **A**–**E**. *Feistiella bijuescensis* from sample Nazarcea F6/113. A. apical view, LPB_IV_CH 101; B. lateral view, LPB_IV_CH 102; C. lateral views, LPB_IV_CH 103; D. basal view, LPB_IV_CH 104; E. interior basal view showing the basal plate, LPB_IV_CH 105. **F**–**H**. *Feistiella* sp. from sample Saligny F1/74–75.5. F. apical view, LPB_IV_CH 106; G. lateral view, LPB_IV_CH 107; H. basal view, LPB_IV_CH 108. **I**. *Latochara* sp., lateral view, from sample Nazarcea F8/114, LPB_IV_CH 109. **J**–**M**. *Mesochara dobrogeica* sp. nov. from sample Nazarcea F6/113. J. apical view, LPB_IV_CH 110; K. lateral view, LPB_IV_CH 110; L. lateral views, LPB_IV_CH 111; M. basal view, LPB_IV_CH 112. **N**–**R**. aff. *Mesochara harrisii*. N. apical view, sample Nazarcea F6/113, LPB_IV_CH 113; O. lateral view, sample Nazarcea F6/113, LPB_IV_CH 114; P. lateral view, sample Nazarcea F6/25, LPB_IV_CH 115; Q. lateral view, sample Nazarcea F6/25, LPB_IV_CH 116; R. basal view, sample Nazarcea F6/25, LPB_IV_CH 117. **S**–**W**. *Sphaerochara andersonii* from sample Nazarcea F6/25. S. apical view, LPB_IV_CH 118; T. lateral view, LPB_IV_CH 118; U. lateral view, LPB_IV_CH 119; W. basal view, LPB_IV_CH 120.

*Material.* A few poorly preserved gyrogonites were collected from sample Nazarcea F8/114 (Table 1). Two specimens were measured.
*Description.* Gyrogonites are small, 377 μm in length and 310 μm in width on average. They display subglobular shape and an ISI of 122. Nine or ten spiral turns can be observed in the lateral view (Fig. 4I). The gyrogonite shape and apical structure warrant the inclusion of these gyrogonites in the genus *Latochara*. At the rim of the summit, spiral cells turn abruptly upwards into an almost vertical position to form a small pyramidal projection in the centre (Fig. 4I). The apical pore cannot be observed due to the poor preservation of the gyrogonites. The base is slightly tapering or could be rounded.
*Remarks.* Poor preservation and an insufficient number of gyrogonites from only one sample hinder a detailed taxonomic attribution and comparison with other *Latochara* species.
*Distribution. Latochara* gyrogonites have been found in several Mesozoic basins in France, Ukraine, and the USA. It also seems to occur in the Palaeocene of China (Feist et al., 2005 and references therein).
*Age.* The genus *Latochara* displays a wide biostratigraphic range, occurring in Triassic to Palaeocene sedimentary sequences (Feist et al., 2005). However, in Europe, it disappeared during the Berriasian (Schudack, 1993).

Family Characeae (Richard ex C. Agardh, 1824) emend. Martín-Closas et Schudack, 1991
Subfamily Charoidae Al. Braun in Migula, 1897

Genus *Mesochara* Grambast, 1962
***Mesochara dobrogeica*** Sanjuan, Vicente, Pérez-Cano, Stoica et Martín-Closas, sp. nov.
Fig. 4J–M

*Derivation of name.* From the type locality in the Dobrogea area (south-eastern Romania).
*Holotype.* LPB-_IV_CH 110, collection number of the Laboratory of Palaeontology of Bucharest (Fig. 4J and K).
*Paratypes.* Numbers LPB_IV_CH 111 and LPB_IV_CH 112, collection number of the Laboratory of Palaeontology of Bucharest (Fig. 4L and M).
*Repository.* Laboratory of Palaeontology of Bucharest (University of Bucharest, Romania).
*Type locality.* Nazarcea (borehole F6/113).
*Type stratum.* Marl interval of the Zăvoaia Member located at 113-m-depth in the Nazarcea F6 borehole. This species also occurs in another borehole (F8) in the same locality at a depth of 98-m (Table 1).
*Diagnosis.* Small-sized gyrogonites, ovoidal in shape, with slightly pointed apex and base, and ornamented with apical tubercles. Spiral cells concave, showing nine to eleven turns in the lateral view, without periapical modifications.
*Description of the type population.* Thirteen gyrogonites were measured. Gyrogonites are ovoidal (subovoidal) in shape and small in size, 328–428 μm high (mean 385 μm) and 254–343 μm wide (mean 310 μm), subprolate, with an ISI ranging between 110 and 136 (mean 124). Nine to eleven spiral turns can be observed laterally (Fig. 4K and L). The apex is slightly pointed, showing isolated and small apical tubercles (Fig. 4J). Spiral cells do not show any periapical modification. The base is tapering and pointed. The basal pore is very small and pentagonal in shape. The basal plate is unknown.
*Remarks.* Morphological parameters of this species (size, apex closed by unmodified periapical cells, pointed base and small basal pore) suggests its inclusion in the genus *Mesochara*, although the basal plate is needed to confirm this. The presence of well-defined apical tubercles distinguishes this species from other Cretaceous *Mesochara* species and represents the oldest occurrence of an ornamented gyrogonite in the fossil record of the Charoidae/Chareae Al. Braun in Migula, 1897.
*Distribution.* This is the first known occurrence of this species.
*Age.* Early Cretaceous (Berriasian), based on the associated charophytes and ostracods.

aff. ***Mesochara harrisii*** (Mädler, 1952) Shaikin, 1967
Fig. 4N–R

*Material.* Several gyrogonites were extracted from all the studied drilling boreholes. However, they occur only in moderate abundance (Table 1). Ten gyrogonites were measured from sample Saligny F1/74–75.5 and ten specimens from sample Nazarcea F6/113.
*Description.* Gyrogonites are very small, 235–377 μm high (mean 317 μm) and 189–287 μm wide (mean 241 μm), subprolate to prolate, with an ISI ranging between 114 and 158 (mean 128). Six to nine (commonly eight) spiral turns can be observed in the lateral view (Fig. 4O–Q). The apex is rounded or slightly pointed, showing the junction of apical cells without any periapical modification (Fig. 4N). The base is pointed and occasionally projected, forming a short basal column. The basal pore is pentagonal in shape and very small in diameter (Fig. 4R). The basal plate has not been observed, making the genus attribution of these gyrogonites to *Mesochara* (undivided basal plate) or *Tolypella* (divided basal plate in *Tolypella* section *Tolypella*) difficult, as already pointed out by Martín-Closas et al. (2018). The gyrogonites studied can be compared to *Mesochara stipitata* (Wang, 1965) Wang, 1981 since some of them display a small basal projection. However, this character is not regularly present in the populatins studied. On the other hand, *M. harrisii* can be distinguished from the contemporary species *Mesochara voluta* (Peck, 1937) Grambast, 1965 since the latter shows a characteristic subovoidal shape and a lower ISI.
*Distribution. M. harrisii* is considered a cosmopolitan species. It has been identified in Lower Cretaceous non-marine deposits from western European basins (Iberian Chain, Subalpine Chains, and Jura Mountains), China, Japan, and the United States (Martín-Closas, 2000).
*Age.* Early Cretaceous (Martín-Closas, 2000).

Subfamily Nitelloideae Al. Braun in Migula, 1897

Genus *Sphaerochara* (Mädler, 1952) emend. Soulié-Märsche, 1989
***Sphaerochara andersonii*** Feist, Lake et Wood, 1995
Fig. 4S–W

*Material.* A small number of gyrogonites were recovered from two samples in Nazarcea, i.e., F6/113 and F6/25 (Table 1). Twenty-one specimens were measured from the sample Nazarcea F6/25.
*Description.* Gyrogonites are small, 363–471 μm high (mean 411 μm) and 291–353 μm wide (mean 316 μm), subprolate to prolate in shape, with an ISI ranging between 115 and 148 (mean 133). Spiral cells are 133 μm wide (Fig. 4T), usually convex or flat, occasionally thick, forming a wavy mid-cellular crest (Fig. 4U). Eleven to fourteen (commonly twelve) spiral turns can be observed in the lateral view (Fig. 4T and U). The gyrogonite base is rounded, showing a large pentagonal basal pore of up to 70 μm. The basal plate is in the shape of a pentagonal prism, very large, and can be distinguished from the outside. Spiral cells show a slight narrowing at the periapical area of the gyrogonite, bearing well-developed apical nodules, which may form a rosette (Fig. 4S).
*Distribution.* This species was first reported by Feist et al. (1995) from a drilling core in the English Weald (UK). Martín-Closas (2000) recovered *S. andersonii* from lacustrine deposits in the Iberian Chain (Spain). This study describes *S. andersonii* in eastern Europe for the first time, which enhances its biostratigraphic significance regarding basin correlation.
*Age.* Hauterivian to late Barremian (Martín-Closas, 2000).

**Table 1**
List of charophyte taxa and their relative abundance based on a semi-quantitative visual estimation.

| Drill number | Drill deep (m) | Species | | | | | | | | | | | | | | | | | | | | Locality |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Porocharaceae | | | Characeae | | | Clavatoraceae | | | | | | | | | | | | | | |
| | | *Feistiella bijuesensis* | *Feistiella* sp. | *Latochara* sp. | aff. *Mesochara harrisii* | *Mesochara dobrogeica* | *Sphaerochara andersonii* | *Atopochara trivolvis* var. *micrandra* | *Atopochara trivolvis* var. *triquetra* | *Globator maillardii* var. *nurrensis* | *Globator maillardii* var. *trochiliscoides* | *Globator maillardii* var. *biutricularis* | *Clavator bilateralis* | *Clavator grovesii* var. *grovesii* | *Clavator grovesii* var. *discordis* | *Clavator grovesii* var. *jiuquanensis* | *Clavator harrisii* var. *reyi* | *Clavator ampullaceous* var. *latibracteatus* | *Nodosoclavator bradleyi* | *Hemiclavator adnatus* | *H. neimongolensis* var. *posticecaptus* | |
| F1 | 32,2 |  |  |  | · |  |  |  |  |  |  |  |  | · |  |  |  |  | · |  |  | Saligny |
| | 34,2 |  |  |  |  |  |  |  |  |  |  |  | • | · |  |  |  |  |  |  |  | |
| | 38 | · |  |  | · |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |
| | 40 |  |  |  |  |  |  |  |  |  |  |  |  | · |  |  |  |  | • |  |  | |
| | 59–59,5 |  |  |  | • |  |  |  |  |  |  |  | • | • | • |  |  |  | · |  |  | |
| | 74–75,5 |  | · |  | • |  |  |  |  |  |  |  |  | ⬤ | • |  |  |  | · |  |  | |
| | 90,5 |  |  |  |  |  |  | · |  |  |  |  |  | • |  |  |  |  | • |  |  | |
| | 96 |  |  |  |  |  |  | · |  |  |  |  |  | · |  |  |  |  |  |  |  | Dunărea |
| | 105,5 | · |  |  |  |  |  |  |  |  |  |  |  | · |  |  |  |  | · |  |  | |
| | 143 | · |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | · |  |  | |
| F4 | 116 |  |  |  |  |  |  |  |  |  |  |  | • |  |  |  |  |  | ● |  | · | Poarta Albă |
| 31 outcrop | 78 | • |  |  |  |  |  | • |  |  |  |  | • | • |  |  |  |  |  | • |  | Cernavodă Ecluza |
| F6 | 25 |  |  |  | · |  | • |  | • |  |  |  |  |  |  | · |  | · |  |  |  | Nazarcea |
| | 31 |  |  |  |  |  |  |  | · |  |  |  |  |  |  | · |  | · | · |  |  | |
| | 113 | • |  |  | • | · |  |  |  |  |  |  | • |  | · |  |  |  | · |  |  | |
| F8 | 93 | · |  |  | · |  |  | · |  |  |  |  | · |  | · |  |  |  | · |  |  | |
| | 98 | • |  |  | • | · |  |  |  |  |  |  | · | · | · |  |  |  | · |  |  | |
| | 114 |  |  | · |  |  |  |  |  |  |  |  | ● |  |  |  |  |  | • |  |  | |
| | 138 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | • |  |  | |
| F106 | 12–13 |  |  |  |  |  |  | · |  |  |  |  | • | • |  |  |  |  |  |  |  | Ilie Barza |
| | 14–15 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |
| | 19,5 | · |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | · |  |  | |
| | 20,5 | · |  |  |  |  |  |  |  |  |  |  | • | • |  |  |  |  | · |  |  | |
| | 21 | • |  |  |  |  |  |  |  |  |  |  | · | • |  |  |  |  | · |  |  | |
| | 23 |  |  |  |  |  |  |  |  |  |  |  |  | • |  |  |  |  |  |  |  | |
| | 26 | · |  |  |  |  |  |  |  |  |  |  | · | · |  |  |  |  |  |  |  | |
| | 27 |  |  |  |  |  |  |  |  |  |  |  |  | · |  |  |  |  | · |  |  | |
| | 28 |  |  |  |  |  |  |  |  |  |  |  | · | • |  |  |  |  | · |  |  | |
| | 29 |  |  |  |  |  |  |  |  |  |  |  | · |  |  |  |  |  | · |  |  | |
| | 32 | • |  |  | · |  |  |  |  |  |  |  | · |  |  |  |  |  | · |  |  | |
| | 33 |  |  |  |  |  |  |  |  |  |  |  | • |  |  |  |  |  |  |  |  | |
| | 35 |  |  |  |  |  |  |  |  |  |  |  |  | ● | • |  |  |  | · |  |  | |
| | 36 | · |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |
| | 39 |  |  |  |  |  |  |  |  |  |  |  | • |  |  |  |  |  |  |  |  | |
| | 40 | • |  |  | · |  |  |  |  |  |  |  |  | ⬤ |  |  |  |  | • |  |  | |
| | 46 |  |  |  |  |  |  |  |  |  |  |  | ⬤ |  |  |  |  |  |  |  |  | |
| F130 | 71 |  |  |  |  |  |  |  |  |  |  |  | • |  |  |  |  |  |  |  |  | Cernavodă |
| | 86 | • |  |  |  |  |  |  |  |  |  |  | · | ● |  |  |  |  | • | • | ● | |
| F132 | 65 |  |  |  |  |  |  |  |  |  |  |  | ⬤ |  |  |  |  |  |  |  |  | Cernavodă POD |
| | 73 |  |  |  |  |  |  |  |  | ● |  |  | · |  | · |  |  |  | ⬤ | ● | • | |
| F133 | 187 |  |  |  | • |  |  |  |  |  |  |  |  | ● |  |  |  |  |  | • | • | Fetesti Baltă |
| | 203a |  |  |  |  |  |  |  |  |  |  |  | • |  |  |  |  |  |  | · |  | |
| F134 | 199 |  |  |  |  |  |  |  |  |  |  |  | · | · |  |  |  |  | · | · |  | Cernavodă |
| FM Ap 5 | 47.5 |  |  |  |  |  |  |  | · |  | · | · |  |  |  | · |  |  |  |  |  | |
| PH3 | 57.6–56.8 |  |  |  | • |  |  |  | • |  | · | • |  |  |  | · | ● |  |  |  |  | |

**Relative abundance** · 1–10 • 10–50 ● 50–100 ⬤ >100

Family Clavatoraceae Pia, 1927
Subfamily Atopocharoidae Grambast, 1968 emend. Martín-Closas ex Schudack, 1993

Genus *Globator* Grambast, 1966
*Globator maillardii* (Saporta, 1981) Grambast, 1966 emend. Martín-Closas ex Schudack, 1993
***Globator maillardii* var. *nurrensis*** Pecorini, 1969
Fig. 5A–D

*Material*. Several well-preserved utricles have been recovered from the sample F132/73 in Cernavodă (Table 1). Seven utricles of this species have been measured for the description.
*Description*. Gyrogonites are large and globular, bottle-shaped, non-calcified; known from their impressions on the internal wall of the utricle. Utricles are very variable in size, ranging between 882–1417 μm high (mean 1247 μm) and 764–1078 μm wide (mean 934 μm), with an average ISI of 133. The utricle displays a subspherical or fusiform shape, showing a long apical neck (Fig. 5B and C). Occasionally, the apical neck can be very extended (Fig. 5C). The apical pore (Fig. 5A) is circular in shape and large in diameter (ca. 190 μm). The utricle is organised in three units of symmetry, which are clearly recognised from its basal view (Fig. 5D). Each unit consists of one diamond-shaped to long pentagonal, short basal cell, to which three elongated cells are attached. Two more elongated cells embrace this central structure and can be subdivided into two parts by a suture above the equator of the utricle (see the arrow in Fig. 5B). The five elongated cells (two lateral and three central) of each unit coil clockwise from the basal part of the utricle to the apex. Nine or ten turns can be observed in the lateral view (Fig. 5B and C).
*Distribution*. Utricles of this species were first illustrated and named charophyte oogoniä from the region studied by Malz (1969). This species was first described formally from La Nurra d'Alguer, in Sardinia (Italy) and later reported in the Iberian Chain, Catalan Coastal Chains, Basque-Cantabrian Chain, Prebetic Chain (Spain), Lusitanian Basin (Portugal), and Jura Mountains in France and Switzerland (Martín-Closas, 2000 and references therein).
*Age*. Late Berriasian, based on ammonite correlation in the Jura Mountains, Switzerland (Détraz and Mojon, 1989).

***Globator maillardii* var. *trochiliscoides*** (Grambast, 1966) Martín-Closas, 1996
Fig. 5E–H

*Material*. A few well-preserved utricles have been recovered from only one sample, Cernavodă FMAp 5/47.5 m (Table 1). Two utricles have been measured for the description.
*Description*. Gyrogonites are globular, non-calcified and known from their impressions on the internal wall of the utricle. Utricles are globular, bottle-shaped and very large, at 1026 μm high and 923 μm wide, with an ISI of 111 (Fig. 5F and G), displaying a short and broad apical neck. Apical pore is large (115 μm in diameter) and circular in outline (Fig. 5E). The base is rounded or slightly pointed, showing a small basal pore (Fig. 5H). The utricle is organised in three identical units of symmetry, which can be recognised at the base. Each unit is formed by five elongated cells; three in a central position, converging to the basal pore without reaching it, flanked by two more elongated cells, one at either side of this central group and directly attached to the basal pore. The 15 utricle cells coil clockwise to the apex, displaying 17 convolutions in the lateral view (Fig. 5F and G).
*Distribution*. This species has already been mentioned by Avram et al. (1993) in South Dobrogea (south-eastern Romania). However, no clear illustration or proper description was provided. *G. maillardii* var. *trochiliscoides* is abundant in Barremian lacustrine deposits from the Iberian Chain (Spain), Algarve (Portugal), Subalpine Chain (France), Jura Mountains (Switzerland), Middle and High Moroccan Atlas (Morocco), and Tunisian Atlas (Tunisia), and it represents a characteristic taxon of the western islands of the Cretaceous Tethyan Archipelago (Martín-Closas, 2000).
*Age*. Early Barremian to early Aptian (Martín-Closas, 2000).

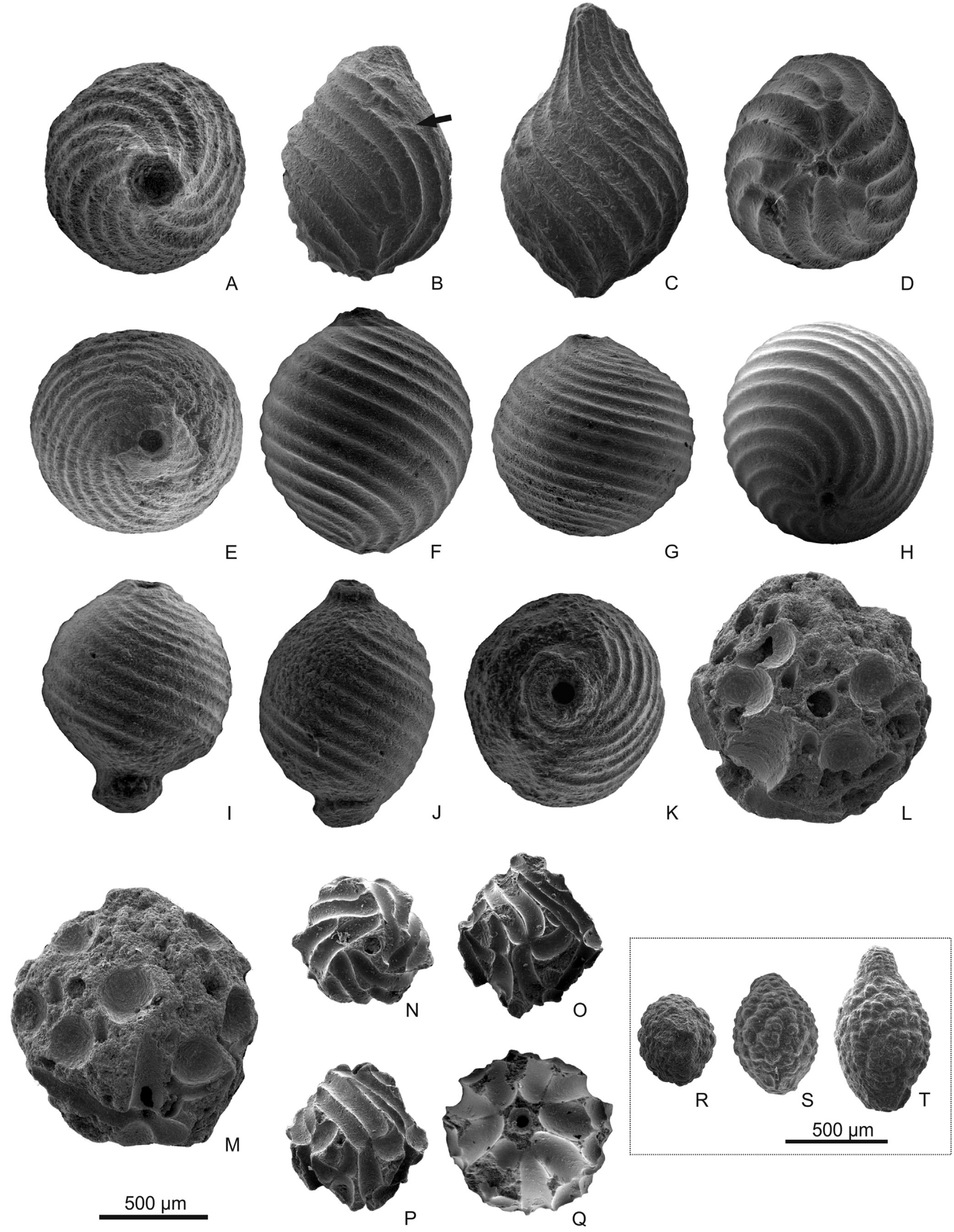
***Globator maillardii* var. *biutricularis*** Vicente et Martín-Closas, 2013
Fig. 5I–K

*Material*. A few utricles have been recovered from one sample from Cernavodă, i.e., FM Ap5/47.5 m (Table 1). Two utricles of this variety have been measured for the description.
*Description*. Utricles are very large, 1105 μm high and 822 μm wide, with an ISI of 135, and globular in shape (Fig. 5I and J). The utricle structure is identical to that of the var. *trochiliscoides* but it shows a characteristic uncalcified ring around the basal pore (Fig. 5K), which was wrongly interpreted as representing a superimposed utricle layer by Vicente and Martín-Closas (2013), as recently noted by Pérez-Cano et al. (2020).
*Distribution*. This variety of *Globator maillardii* has so far been reported in the Iberian Chain in NE Spain (Vicente and Martín-Closas, 2013) and in one locality of the Central Tunisian Atlas (Trabelsi et al., 2016).
*Age*. Late Barremian to early Aptian (Vicente and Martín-Closas, 2013).

Genus *Atopochara* Peck, 1938.
*Atopochara trivolvis* (Peck, 1938) emend. Martín-Closas, 1996
***Atopochara trivolvis* var. *micrandra*** (Grambast, 1967) Martín-Closas, 1996
Fig. 5L and M

*Material*. A few utricles from five samples in Saligny, Dunărea, Cernavodă, Nazarcea, and Ilie Barza (Table 1). Two utricles were measured from the outcrop sample Cernavodă Ecluza 31/78.
*Description*. Gyrogonites are globular, non-calcified and known from their impressions on the internal wall of the utricle. Utricles are very large, 1187 μm high and 1109 μm wide, and globular in shape (Fig. 5L and M). They display a triradiate symmetry. Each unit of symmetry is formed by three main branches attached to a short basal cell, directly connected to the basal pore. Each of the three main branches trifurcates once or twice, forming fork-like structures that bear the antheridia, as described by Grambast (1967, 1968). About ten to fifteen antheridial impressions can be recognised, each having a diameter of about 240 μm and showing at least two out of four antheridial shields.
This species differs from its ancestor *A. trivolvis* var. *horrida* in its larger utricle size and also because the vegetative structure of *A. trivolvis* var. *horrida* is hidden by the larger size of the antheridial impressions on the utricle wall.
*Distribution*. This species has already been mentioned in South Dobrogea by Avram et al. (1993) and in the nearby Pre-Dobrogean Basin (Ukraine) by Shaikin (1976). *A. trivolvis* var. *micrandra* represents an extensively distributed taxon occurring in the northern part of the Cretaceous Tethyan archipelago. It has been reported in Spain (Iberian Chain, Catalan Coastal Chain, Basque-Cantabrian Chain and Prebetic Chain), Portugal (Algarve), Switzerland (Jura Mountains), and Italy (Sardinia) (Martín-Closas, 2000 and references therein).
*Age*. Early Berriasian to late Hauterivian (Martín-Closas, 2000 and references therein).

***Atopochara trivolvis* var. *triquetra*** (Grambast, 1967) Martín-Closas, 1996
Fig. 5N–Q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500 μm
500 μm

*Material*. Several utricles of this variety were recovered from four samples in Nazarcea and Cernavodă (Table 1). Six utricles were measured from sample Nazarcea F6/25.

*Description*. Gyrogonites are globular, non-calcified and known from their impressions on the internal wall of the utricle. Utricles are large and very variable in size, 673–1155 μm high (mean 866 μm) and 663–985 μm wide (mean 759 μm), bi-tetrahedral in shape and with a triradiate symmetry formed by three identical bract-cell units (Fig. 5O and P). Each unit is formed by three equally large bract cells at the base, that are attached to the basal pore (Fig. 5Q). The two left-hand basal cells trifurcate with two long, helicoidal cells on the left and one short, rounded cell on the right. The third bract-cell unit bifurcates into two small diamond-shaped cells that flank a central cell bearing the impression of one antheridial shield. The antheridium marks are, in this case, smaller than in the variety *A. trivolvis micrandra*.

*Distribution*. *A. trivolvis* var. *triquetra* was found in the nearby Pre-Dobrogean Basin in Ukraine by Shaikin (1976). Avram et al. (1993) reported it in South Dobrogea (Romania). This variety displays a worldwide distribution occurring in almost all continents except North America and Australia (Martín-Closas and Wang, 2008 and references therein).

*Age*. Latest Hauterivian to early Aptian (Martín-Closas, 2000; Martín-Closas et al., 2009).

Subfamily Clavatoroidae (Grambast, 1969) emend. Martín-Closas ex Schudack, 1993

Genus *Nodosoclavator* Maslov, 1961
***Nodosoclavator bradleyi*** (Harris, 1939) Grambast, 1969
Fig. 5R–T

*Material*. It represents a common taxon occurring in all the localities and drilling boreholes studied (Table 1). Seven utricles have been measured from sample F4/116 in Poarta Albă.

*Description*. This species shows a clavatoroid gyrogonite. Utricles are elongated and bottle-shaped (Fig. 5S and T), very variable in size, 586–821 μm high (mean 623 μm) and 351–478 μm wide (mean 385 μm), with an ISI of 167. The utricle is mostly formed by a nodular layer, with nodules roughly aligned following the spiral-cell sutures (Fig. 5S and T). The superimposed, structured utricle layer can be observed only at its base. It is formed by small, digitated bract cells which are arranged radially around the basal pore.

*Distribution*. *N. bradleyi* is a cosmopolitan taxon occurring in European and Chinese basins (Wang et al., 1976; Huang, 1985; Martín-Closas, 2000 and references therein). Moreover, this species has recently been reported in the Western Interior Basin in the USA (Martín-Closas et al., 2013). Peck (1957) found this species (under the name of *Clavator nodosus*) in the Aptian from the Western Interior.

*Age*. Tithonian-Aptian (Martín-Closas, 2000).

Genus *Clavator* (Reid et Groves, 1916) emend. Martín-Closas ex Schudack, 1993
***Clavator bilateralis*** Peck, 1957 emend Martín-Closas, Sames et Schudack 2013
Fig. 6A–D

*Material*. This species occurs abundantly in almost all the drilling boreholes studied (Table 1). Fourteen utricles from sample Nazarcea F8/14 were measured for the description.

*Description*. This species shows a clavatoroid gyrogonite. Utricles are small, showing a clear bilateral symmetry. In the lateral view they are 430–728 μm high (mean 513 μm) and 373–527 μm wide (mean 472 μm). The utricle consists of an internal nodular layer covered completely by a structured layer. This layer is formed by the impression of the phylloid in an adaxial position, an abaxial elongated bract cell opposite it and two lateral composite bract-cell units displaying a pinnate structure (Fig. 6B and C). Each lateral bract-cell unit is formed by a single wide, vertical cell in the centre, attached to the utricle base, occasionally reaching mid-height of the utricle, and bearing one lancet-shaped cell at the top and two to three symmetrical pairs of elongated bract cells on each side, arranged opposite each other (Fig. 6B and C). Both the abaxial long cell and the lateral composite bract-cell units are attached to a rounded basal pore (Fig. 6D). The apical pore is large (100 μm in diameter) and displays a circular outline (Fig. 6A).

*Remarks*. The utricle structure of this species in the South Dobrogea Basin corresponds well to the populations described by Peck (1957) and Martín-Closas et al. (2013), from the Lakota and Cedar Mountain formations in the USA. The main difference between both North American populations and the Romanian populations studied here, lies in the number of pinnate cells at the lateral bract-cell units, which ranges from five to seven in Romanian utricles, while the American populations show a wider range of intraspecific variation, including utricles with only three pinnate cells (Martín-Closas et al., 2013). The latter correspond, in fact, with the holotype designated by Peck (1957). However, the illustrations of this species provided by Avram et al. (1993) suggest that this morphotype may also occur in Romania.

*Distribution*. Avram et al. (1993) had already cited *C. bilateralis* (under the name of its younger synonym, *Clavator minutus*) in South Dobrogea (south-eastern Romania). Shaikin (1976) also found this taxon in the Pre-Dobrogean Basin (south-eastern Ukraine). However, these references were not considered in subsequent charophyte studies, probably due to insufficient description and illustration. *C. bilateralis* has been re-defined and illustrated with modern techniques only very recently from the Western Interior Basin of the United States by Martín-Closas et al. (2013). The present study confirms the occurrence of this species outside North America.

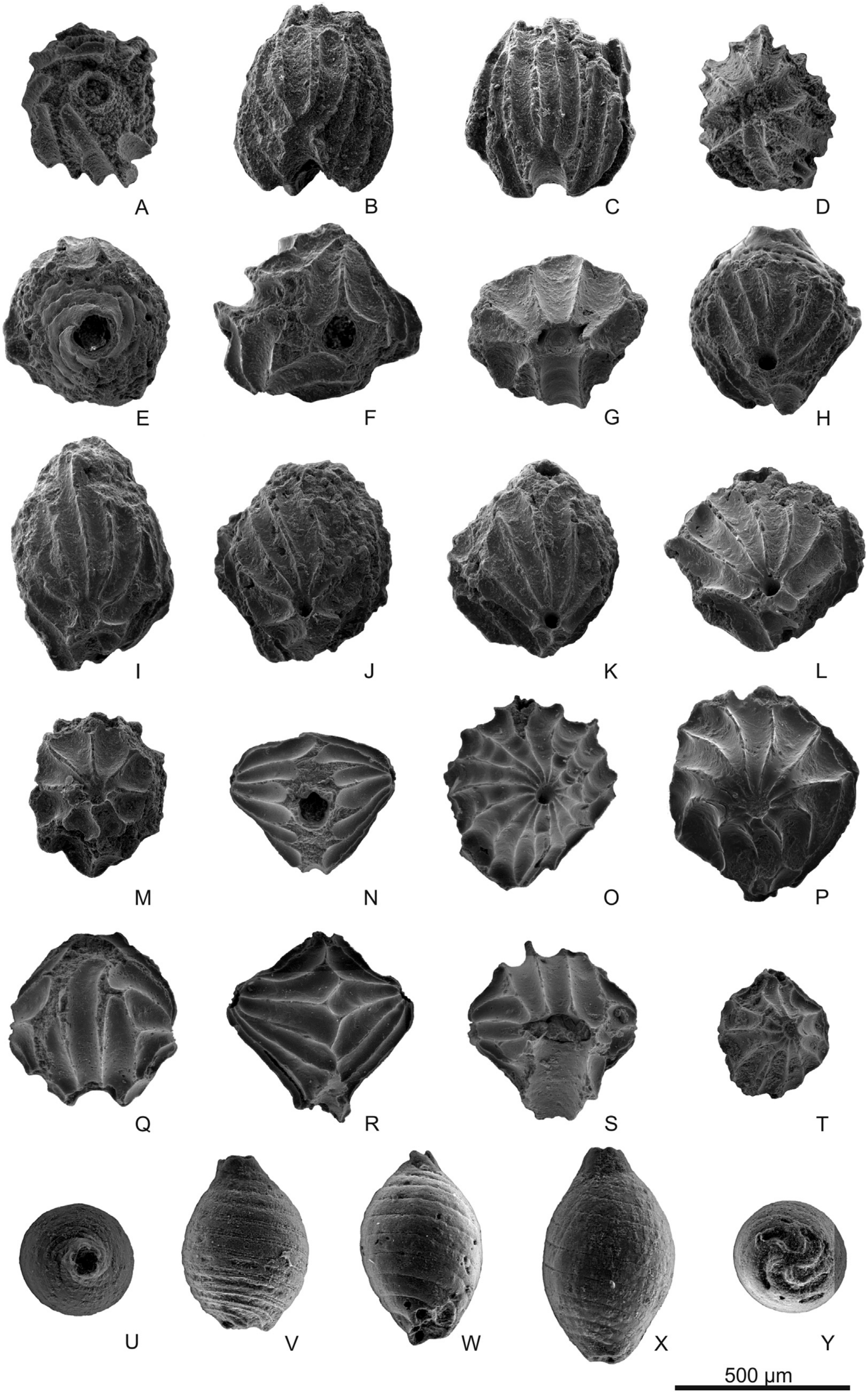
*Age*. Early Berriasian to earliest Valanginian (Martín-Closas et al., 2013).

*Clavator grovesii* (Harris, 1939) emend. Schudack, 1993
***Clavator grovesii* var. *grovesii*** (Harris, 1939) Martín-Closas, 1996
Fig. 6E–K

*Material*. Well-preserved utricles of this variety dominate in many samples of the studied localities (Table 1). Sixteen utricles from the sample Saligny F1/74–75.5 were measured for the description.

*Description*. Gyrogonites are clavatoroid, while utricles are oval and laterally flattened (Fig. 6H–K). They are medium in size, 489–674 μm high (mean 561 μm) and 390–517 μm wide (mean 466 μm). The utricle is formed of an internal nodular layer and an external structured layer displaying bilateral symmetry. The external layer is

**Fig. 5.** Utricles from South Dobrogea (south-eastern Romania). **A**–**D**. *Globator maillardii* var. *nurrensis* from sample Cernavodă F132/73. A. apical view, LPB_IV_CH 121; B. lateral view, LPB_IV_CH 122; C. lateral view, LPB_IV_CH 123; D. basal view, LPB_IV_CH 124. **E-H**. *Globator maillardii* var. *trochiliscoides* from sample Cernavodă Ph3/57.6–56.8. E. apical view, LPB_IV_CH 125; F. lateral view, LPB_IV_CH 126; G. lateral view, LPB_IV_CH 127; H. basal view, LPB_IV_CH 126. **I**–**K**. *Globator maillardii* var. *biutricularis* from sample Cernavodă Ph3/57.6–56.8. I. lateral view, LPB_IV_CH 128; J. lateral view, LPB_IV_CH 129; K. basal view, LPB_IV_CH 130. **L**–**M**. *Atopochara trivolvis* var. *micrandra* from sample Cernavodă Ecluza 31/78. L. apical view, LPB_IV_CH 131; M. lateral view, LPB_IV_CH 132. **N**–**Q**. *Atopochara trivolvis* var. *triquetra* from sample Nazarcea F6/25. N. apical view, LPB_IV_CH 133; O. lateral view, LPB_IV_CH 134; P. lateral view, LPB_IV_CH 135; Q. basal view, LPB_IV_CH 136. **R**–**T**. *Nodosoclavator bradleyi*. R. apical view, sample Poarta Albă F4/116, LPB_IV_CH 137; S. lateral view, sample Poarta Albă F4/116, LPB_IV_CH 138; T. lateral view, sample Cernavodă F130/86, LPB_IV_CH 139.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Y
500 μm

formed by a portion of the branchlet and three bract cells connected to the basal pore (Fig. 6F). One of the bract cells is located in an abaxial position, opposite the branchlet. The other two bract cells are shorter and are located in a lateral position, each bearing a lateral fan at the tip. Eight lancet-shaped fan cells can be distinguished, completely or almost completely covering the utricle surface (Fig. 6H–K). On each side of the lateral bract cell a smaller and wider cell can be observed in the lateral view. The apical pore is large (Fig. 6E and F), 98 μm in diameter, sometimes showing a rose-shaped outline (Fig. 6E). The basal pore is also large, 120 μm in diameter, showing the base of the internal gyrogonite and its basal plate (Fig. 6G).

*Distribution*. *C. grovesii* var. *grovesii* represents a cosmopolitan taxon occurring in several western European basins, China, and North America (Martín-Closas et al., 2013; Martín-Closas, 2015). This species has also been cited in South Dobrogea (south-eastern Romania) by Avram et al. (1993). However, no detailed description or illustration was provided by these authors. The present study confirms the occurrence of this variety of *Clavator grovesii* in the eastern Cretaceous Tethyan archipelago.

*Age*. Tithonian to earliest Valanginian (Martín-Closas et al., 2013).

***Clavator grovesii* var. *discordis*** (Shaikin, 1976) Martín-Closas, 1996
Fig. 6L–M

*Material*. It occurs in minor amounts, associated with the previous variety *C. grovesii* var. *grovesii,* in several samples from almost all localities (Table 1). Four specimens from sample Nazarcea F6/113 were measured.

*Description*. The fructification of this variety has a similar utricle structure to the previous variety, except for the lateral bract-cell fans. Eight lancet-shaped fan cells can be distinguished covering the utricle surface, six elongated cells are arranged upwards and two short cells downwards at the base of the fan (Fig. 6L and M). On each side of the lateral bract cell, a smaller and wider cell can be observed in the lateral view.

*Distribution*. This species was first described by Shaikin (1976) in Odessa (Ukraine). Later, it was widely reported in non-marine deposits from western European countries such as Spain, Portugal, Germany, France, and the United Kingdom (Martín-Closas, 2000 and references therein). Moreover, Wang and Lu (1982) found this species in China.

*Age*. According to Schudack (1993) this variety would have extended through the whole Berriasian.

***Clavator grovesii* var. *jiuquanensis*** (Wang, 1965) Grambast, 1970 emend. Martín-Closas, 1996.
Fig. 6N–T

*Material*. A few utricles in four samples from Nazarcea and Cernavodă (Table 1). Six utricles were measured from the sample Cernavodă FMAp5/47.5.

*Description*. Gyrogonites are clavatoroid. Utricles are medium in size, 419–650 μm high and 365–618 μm wide, bi-conical in shape, and formed of two layers, i.e., the internal nodular layer and the external structured layer. The external layer contains the impressions of the phylloid and three bract cells, including an abaxial bract cell opposite the phylloid (Fig. 6Q) and two lateral bract-cell units which protrude to form a cone at each side of the utricle and were called shields by Grambast (1970). Each of these lateral units bears 11 to 15 elongated radial cells at the tip (Fig. 6O, P and T), which are generally equidimensional and reach both the base and the apex of the utricle, interdigitating with the corresponding cells of the opposite shield in the abaxial side. The basal pore is large (ca. 112 μm in diameter) and the apical pore is ca. 84 μm in diameter, showing a rose-shaped contour (Fig. 6N and S).

*Remarks*. A few utricles of the studied population show small basal cell impressions, suggesting that these populations contain some primitive forms of the variety, closer to its predecessor *C. grovesii* var. *gautieri* (Grambast, 1970).

*Distribution*. *C. grovesii* var. *jiuquanensis* had already been found in South Dobrogea by Neagu and Georgescu-Donos (1973). Later, Shaikin et al. (1992) reported this species in the nearby Pre-Dobrogean Basin, located about 200 km north-east of the studied basin, in Ukraine. This species is extensively distributed in Europe and Asia (Martín-Closas, 2015 and references therein).

*Age*. Late Barremian to early Aptian (Martín-Closas, 2015).

***Clavator harrisii* var. *reyi*** (Grambast-Fessard, 1980) Martín-Closas, 1996
Fig. 6U–Y

*Material*. Several utricles from sample Cernavodă PH3/57.6–56.8 (Table 1). Three utricles were measured.

*Description*. The fructification consists of an ellipsoidal to bottle-shaped, medium-sized clavatoroid gyrogonite, 512–637 μm high and 356–387 μm wide, devoid of any utricle layer in almost all specimens of the populations. The gyrogonite shows convex tubular spiral cells (the so-called “Ringstruktur” calcification of Schudack, 1993), separated by characteristic undulated sutures (Fig. 6V, W and X) and a wide apical neck with a rose-shaped apical pore of 63 μm in diameter (Fig. 6U).

*Distribution*. This variety of *C. harrisii* has been found in several localities in the western part of the Cretaceous Tethyan archipelago, i.e., Iberian Chain (Spain), Algarve Basin (Portugal), Lusitanian Basin (Portugal), and Central Tunisian Atlas (Trabelsi et al., 2016). The present study also reveals the occurrence of this variety in the eastern part of the Cretaceous Tethyan archipelago.

*Age*. Late Barremian to early Aptian (Martín-Closas, 2000).

*Clavator ampullaceus* (Grambast et Lorch, 1968) Martín-Closas, 1996
***Clavator ampullaceus* var. *latibracteatus*** Sanjuan, Vicente, Pérez-Cano, Stoica et Martín-Closas, var. nov
Fig. 7A–D

1993 *Clypeator corrugatus* – Avram et al., p. 291, Fig. 12e

*Derivation of name*. From the Latin *bractea* (noun) meaning bract cell and *latus* (adj.) meaning large, referring to the large size of these bract cells.

*Holotype*. Number LPB_IV_CH 165. Collection number of the Laboratory of Palaeontology of Bucharest (Fig. 6B).

**Fig. 6.** Utricles from South Dobrogea (south-eastern Romania). **A–D**. *Clavator bilateralis*. A. apical view, sample Ilie Barza F106/39, LPB_IV_CH 140; B. lateral view, sample Cernavodă F132/65, LPB_IV_CH 141; C. lateral view, sample Cernavodă F132/65, LPB_IV_CH 142; D. basal view, sample Ilie Barza F106/39, LPB_IV_CH 143. **E–K**. *Clavator grovesii* var. *grovesii*. E. apical view, sample Ilie Barza F106/40, LPB_IV_CH 144; F. apical view, sample Saligny F1/74–75.5, LPB_IV_CH 145; G. basal view, sample Ilie Barza F106/35, LPB_IV_CH 146; H. lateral view, sample Ilie Barza F106/40, LPB_IV_CH 144; I. lateral view, sample Saligny F1/90.5, LPB_IV_CH 147; J. lateral view, sample Ilie Barza F106/40, LPB_IV_CH 148; K. lateral view, sample Ilie Barza F106/40, LPB_IV_CH 149. **L–M**. *Clavator grovesii* var. *discordis*. L. lateral view, sample Ilie Barza F106/35, LPB_IV_CH 150; M. Lateral view, sample Nazarcea F6/113, LPBIV_CH 151. **N–T**. *Clavator grovesii* var. *jiuquanensis*. N. apical view, sample Cernavodă FMAp5/47.5, LPB_IV_CH 152; O. lateral view, sample Cernavodă FMAp5/47.5, LPB_IV_CH 153; P. lateral view, sample Nazarcea F6/25, LPB_IV_CH 154; Q. adaxial view, sample Nazarcea F6/31, LPB_IV_CH 155; R. abaxial view, sample Cernavodă FMAp5/47.5, LPB_IV_CH 156; S. basal view, sample Cernavodă FMAp5/47.5, LPB_IV_CH 157; T. lateral view, sample Cernavodă FMAp5/47.5, LPB_IV_CH 158. **U–Y**. *Clavator harrisii* var. *reyi* from sample Cernavodă Ph3/57.6–56.8. U. apical view, LPB_IV_CH 159; V. lateral view, LPB_IV_CH 160; W. lateral view, LPB_IV_CH 161; X. lateral view, LPB_IV_CH 162; Y. basal view, LPB_IV_CH 163.

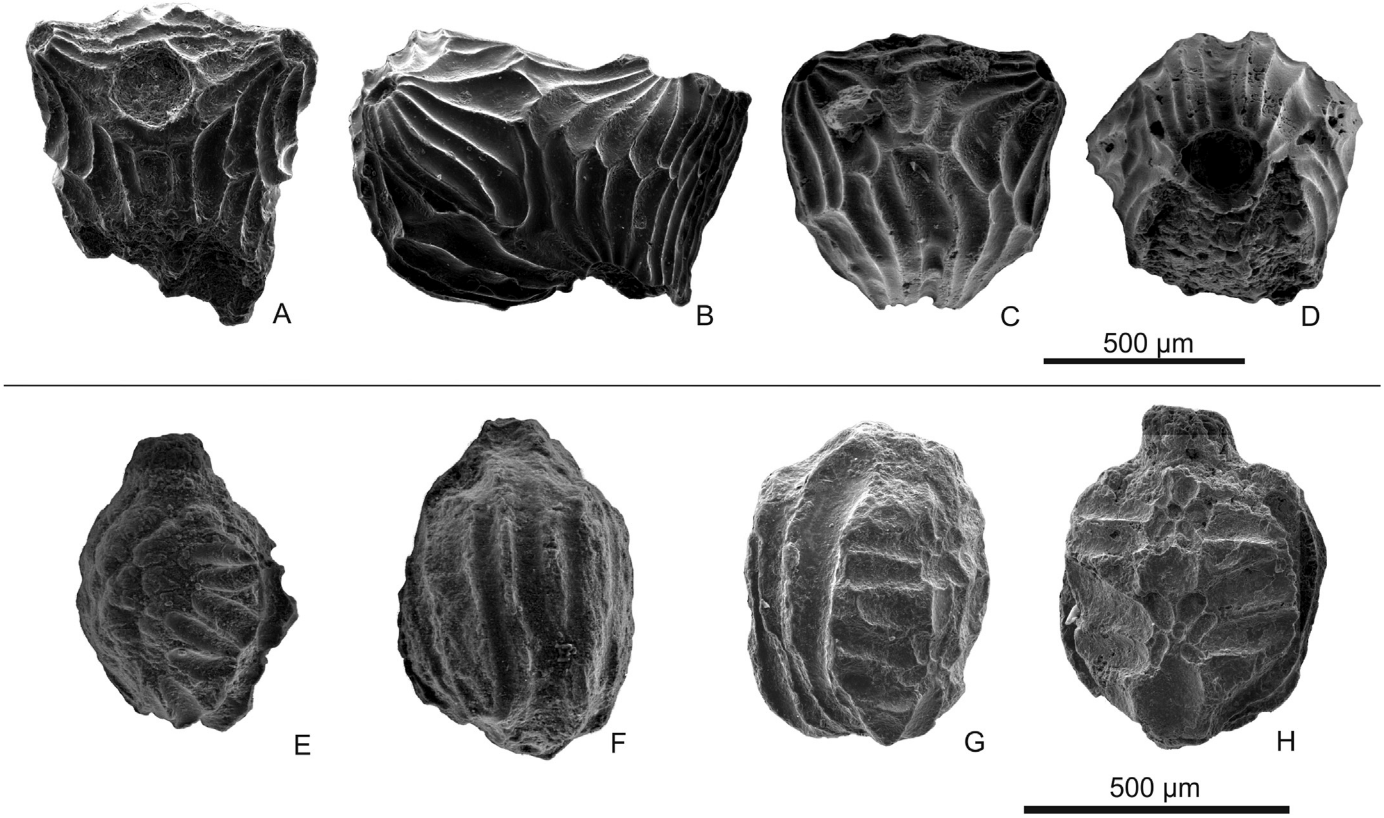

**Fig. 7.** Utricles from South Dobrogea (south-eastern Romania). **A**–**D**. *Clavator ampullaceus* var. *latibracteatus* var. nov. A. apical view, sample Nazarcea F6/25, LPB_IV_CH 164; B. lateral view, sample Nazarcea F6/25, LPB_IV_CH 165; C. abaxial view, sample Nazarcea F6/31, LPB_IV_CH 166; D. basal view, sample Nazarcea F6/31, LPB_IV_CH 167. **E**. lateral view of *Hemiclavator adnatus* from sample Cernavodă F130/86, LPB_IV_CH 168. **F**–**H**. *Hemiclavator neimongolensis* var. *posticecaptus* from sample Cernavodă F130/86. F. abaxial view, LPB_IV_CH 169; G. lateral view, LPB_IV_CH 170; H. adaxial view, LPB_IV_CH 171.

*Paratypes*. Numbers LPB_IV_CH 164, LPB_IV_CH 166, LPB_IV_CH 167. Collection number of the Laboratory of Palaeontology of Bucharest (Fig. 6A, C, and D).

*Type locality*. Nazarcea, sample from the borehole F6, 25 m deep.

*Type stratum*. Marl interval within the Gherghina Formation, located 25 m deep in Nazarcea's borehole F6. This species also occurs at 31 m deep in the same borehole (Table 1).

*Material*. A reduced number of well-preserved utricles from two samples in Nazarcea (Table 1). Three utricles from sample Nazarcea F6/31 were measured for the description.

*Diagnosis*. Utricle bilaterally symmetrical, formed by the adaxial phylloid, two lateral internal bract cells and an abaxial bract cell. The two internal lateral bract cells emerge close to the apical pore, each emitting fourteen bract cells that form a symmetric shield, covering the upper half of the utricle. Eight large basal cells emerge close to the basal pore, completely covering the lower half of the utricle.

*Description*. Gyrogonites are clavatoroid. Utricles are large, 717–822 µm high (769 µm mean) and 740–865 µm wide (802 µm mean), subglobular in shape with an internal nodular layer, non-visible from the outside, and a well-developed structured external layer. The external layer shows the characteristic bilateral symmetry of the Clavatoroidae and contains a well-calcified portion of the phylloid in an adaxial position, the impression of an abaxial bract cell opposite the phylloid (Fig. 7C), and two long lateral bract cells that are not visible from the outside and emerge near the apical part of the utricle surface, forming a small pore (Fig. 7A). Each of the lateral bract cells bears, at its tip, 14 elongated radial cells forming an almost symmetrical conical shield that covers the upper half of the utricle (Fig. 7B). In addition, up to eight elongated basal cells are attached to the basal pore at each side of the utricle, completely covering its lower half (Fig. 7D). The cells of the lateral shields are in contact with the basal cells in a zigzag line near the utricle's equator. A similar indentation occurs between the cells of the two lateral shields. The apical pore is rounded and very large, about 200 µm in diameter (Fig. 7A).

*Remarks*. The new variety shares, in common with *C. ampullaceus* var. *ampullaceus*, the nominal variety from Mount Lebanon (Lebanon and Israel) described by Grambast and Lorch (1968), (1) the occurrence of two long internal lateral bract cells that emerge near the apex and (2) the occurrence of many basal cells. However, the new variety displays only eight basal cells, of large diameter, in contrast to the fourteen thin cells in the nominal variety. There are 14 lateral shield cells in the Romanian variety, while in the nominal variety it ranges from 14 to 18. Moreover, the nominal variety shows very asymmetric lateral shields, with the lower half being much larger than the upper half, while in the new variety the shields are almost symmetrical. Many of the lower shield cells of the nominal variety are long enough to reach the utricle base and are deeply interdigitated with the basal cells, while in the new variety the shield cells do not trespass over the utricle equator and are barely interdigitated with the basal cells. Finally, South Dobrogean utricles from *C. ampullaceus* are ~150 µm smaller than the utricles of the Middle East. However, morphometric parameters are very variable in clavatoraceans and they are not used as a diagnostic character for distinguishing taxa.

*Distribution*. This taxon has already been illustrated in South Dobrogea by Avram et al. (1993), who erroneously named it *Clavator corrugatus*. This species has been found in estuarine-related facies in the Mount Lebanon range (Lebanon and Israel) by Grambast and Lorch (1968) and Granier et al. (2015). Luger and Schudack (2001) documented this species in non-marine rocks from the Al Mado mountain chain (central northern Somalia). The present report represents the first occurrence of *Clavator ampullaceus,* both outside of the Gondwanian realm and in the north-eastern islands of the Cretaceous Tethyan Archipelago.

*Age*. Late Barremian to early Aptian, due to its occurrence in South Dobrogea with the species *C. grovesii* var. *jiuquanensis,* which agrees with the age of its nominal variety from the Middle East (Granier et al., 2015).

Genus *Hemiclavator* Wang et Lu, 1982
***Hemiclavator adnatus*** (Martín-Closas et Grambast-Fessard, 1986) Schudack, 1989
Fig. 7E

*Material*. A reduced number of utricles from six samples in the localities of Cernavodă and Fetesti Baltă (Table 1). Eight utricles from sample Cernavodă F130/86 were measured.

*Description*. Gyrogonites are clavatoroid. Utricles are ellipsoidal and bottle-shaped, measuring 560–720 μm high (mean 601 μm) and 376–453 μm wide (mean 436 μm), with an ISI of 150. The utricle is organised in an internal nodular layer covered only in the adaxial area by an external structured layer. This layer is composed of the phylloid impression, bearing one or two fans of six short lancet-shaped cells, three at each side of the phylloid and attached to one of its nodes (Fig. 7E).

*Distribution*. This species is widely represented in the Iberian Peninsula and it was considered an endemic species by Martín-Closas (2000). The occurrence of this taxon in South Dobrogea indicates a wider palaeogeographic distribution in the Cretaceous Tethyan Archipelago.

*Age*. In the Iberian Peninsula this species is Valanginian to early Barremian in age (Martín-Closas, 2000). However, in one of the studied samples, this species is associated with *Globator maillardii* var. *nurrensis,* suggesting that its time span in Romania began earlier, in the late Berriasian.

*Hemiclavator neimongolensis* Wang et Lu, 1982
***Hemiclavator neimongolensis* var. *posticecaptus*** (Martín-Closas et Grambast-Fessard, 1986) Martín-Closas, 1996
Fig. 7F–H

*Material*. It occurs in four samples from Poarta Albă, Cernavodă, and Fetesti Baltă (Table 1). Ten utricles were measured from sample Cernavodă F130/86.

*Description*. Gyrogonites are clavatoroid. Utricles are bottle-shaped, measuring 559–740 μm high (mean 622 μm) and 408–493 μm wide (mean 471 μm), formed by an internal nodular layer and an external structured layer. The adaxial part of the external layer is very similar to that described for *H. adnatus*. However, the impressions of the phylloid nodes appear to bear a composite system of bracts, with a rosette of five small rounded cells subtending the larger lancet cells (Fig. 7H). In the anterior or abaxial part of the utricle, between four and nine long, filiform cells can be distinguished (Fig. 7F and G). They split radially from the utricle's base and may reach its apical region.

*Distribution*. *H. neimongolensis* var. *posticecaptus* is a well-known species occurring mainly in western European basins such as in the Iberian Chain (Spain), Chartreuse (France), and perhaps in Aït Attab, Morocco (Mojon et al., 2009). This taxon has already been mentioned by Avram et al. (1993) in Romania (South Dobrogea), however, neither the taxonomic description nor the illustrations provided by these authors were clear enough to support this taxonomic attribution. The present work confirms the occurrence of this species in the eastern part of the Cretaceous Tethyan Archipelago.

*Age*. In the Iberian Peninsula this species is Valanginian to early Barremian in age (Martín-Closas, 2000). However, in one of the studied samples this species occurs associated with *G. maillardii* var. *nurrensis,* suggesting that its time span in Romania began earlier, in the late Berriasian.

## 5. Discussion

### 5.1. Biostratigraphy

The charophyte assemblages from the two lithological units studied, the Zăvoaia Member of the Amara Formation, and the Gherghina Formation, are clearly distinguished in terms of taxonomy and biostratigraphy:

| Thickness (m) | Lithostratigraphic units | | Previous studies<br>Ostracod biozonation and relative ages | This study<br>European charophyte biozonation and relative ages |
|---|---|---|---|---|
| | Dragastan et al. (1998) | | Stoica (2007) and Antoniade (2016) after Horne (1995) | Riveline et al. (1996) and Martín-Closas et al. (2009) |
| 5–40 | Gherghina Fm | | Theriosynoecum fittoni<br>Barremian | Ascidiella cruciata-Pseudoglobator paucibracteatus<br>late Barremian–early Aptian<br>~117–122 My |
| 20–40 | Cernavodâ Fm | | Marine deposits | |
| 40–60 | Amara Fm | Variegated Zăvoaia Mbr | Cypridea granulosa<br>middle Berriasian | Globator maillardii nurrensis<br>Upper part of the middle Berriasian<br>~138–140 My |
| | | | Cypridea dunkeri<br>middle Berriasian | |

**Fig. 8.** Biostratigraphic chart showing the relative age of each deposit studied and its correlation with ostracods. Lithostratigraphic units are after Dragastan et al. (1998). Ostracod zonation attributions are after Stoica (2007) and Antoniade (2016), based on the Horne (1995) ostracod biozonation. European charophyte biozonations are after Riveline et al. (1996), Riveline in Hardenbol et al. (1998), and Martín-Closas et al. (2009). Ages are according to Ogg et al. (2016).

a) Zăvoaia Member (Amara Formation): The charophyte assemblage from the upper variegated part of this unit, in the boreholes of Saligny, Dunărea, Nazarcea, and Ilie Barza, is dominated by *Nodosoclavator bradleyi, Clavator bilateralis, C. grovesii* var. *grovesii*, *C. grovesii* var. *discordis*, *Feistiella bijuescensis*, and aff. *Mesochara harrisii*. Other less abundant species include *Atopochara trivolvis* var. *micrandra*, and *Mesochara dobrogeica* sp. nov. This assemblage can be attributed either to the Berriasian *s.l.* or to the middle to late Berriasian (in the samples with *A. trivolvis* var. *micrandra* associated with *C. grovesii* var. *grovesii*), which is compatible with the age given by a previous biostratigraphic study performed in the same unit and based on non-marine ostracods (Stoica, 2007). This author correlated the ostracod assemblage of the Zăvoaia Member with the first two Cypridea zones of the English Purbeck, i.e., the Cypridea dunkeri Zone and part of the Cypridea granulosa Zone of Anderson (1985). Moreover, the ostracod assemblage was also correlated with the lower part of the Theriosynocum forbersi Zone, and the Cypridea dunkeri and Cypridea granulosa subzones of Horne (1995). In addition to the two index species, Stoica (2007) identified other *Cypridea*, i.e., *C. setina* Anderson, 1939, *C. tumescens* Anderson, 1939, *C. tumescens praecursor* Oertli, 1963, *Cypridea* sp.1, *Cypridea* sp.2, and *Cypridea* sp.3. These species occur in the Zăvoaia Member associated with other Purbeckian ostracods belonging to the genera *Rhinocypris*, *Damonella*, *Darwinula*, *Klieana*, *Fabanella*, *Mantelliana*, *Mongolianella*, *Paracypris*, *Pontocyprella*, *Scabriculocypris*, *Stenestroemia*, *Stenocypris*, *Theriosynoecum*, *Timiriasevia*, *Virgatocypris*, and *Wolburgia.* Based on this rich ostracod assemblage, Stoica (2007) provided a relative age of middle Berriasian for the upper variegated part of the Zăvoaia Member (Fig. 8). However, there is a biostratigraphic conflict between charophytes and ostracods in some samples from the localities Cernavodă, Fetesti Baltă, and Poarta Albă, which provided a high number of well-preserved utricles of the species *Hemiclavator adnatus* and *H. neimongolensis* var. *posticecaptus.* Both species are well known in uppermost Berriasian to lowermost Barremian sedimentary sequences in western European basins and are common species of the European charophyte biozones Globator maillardii steinhauseri and Atopochara trivolvis var. triquetra

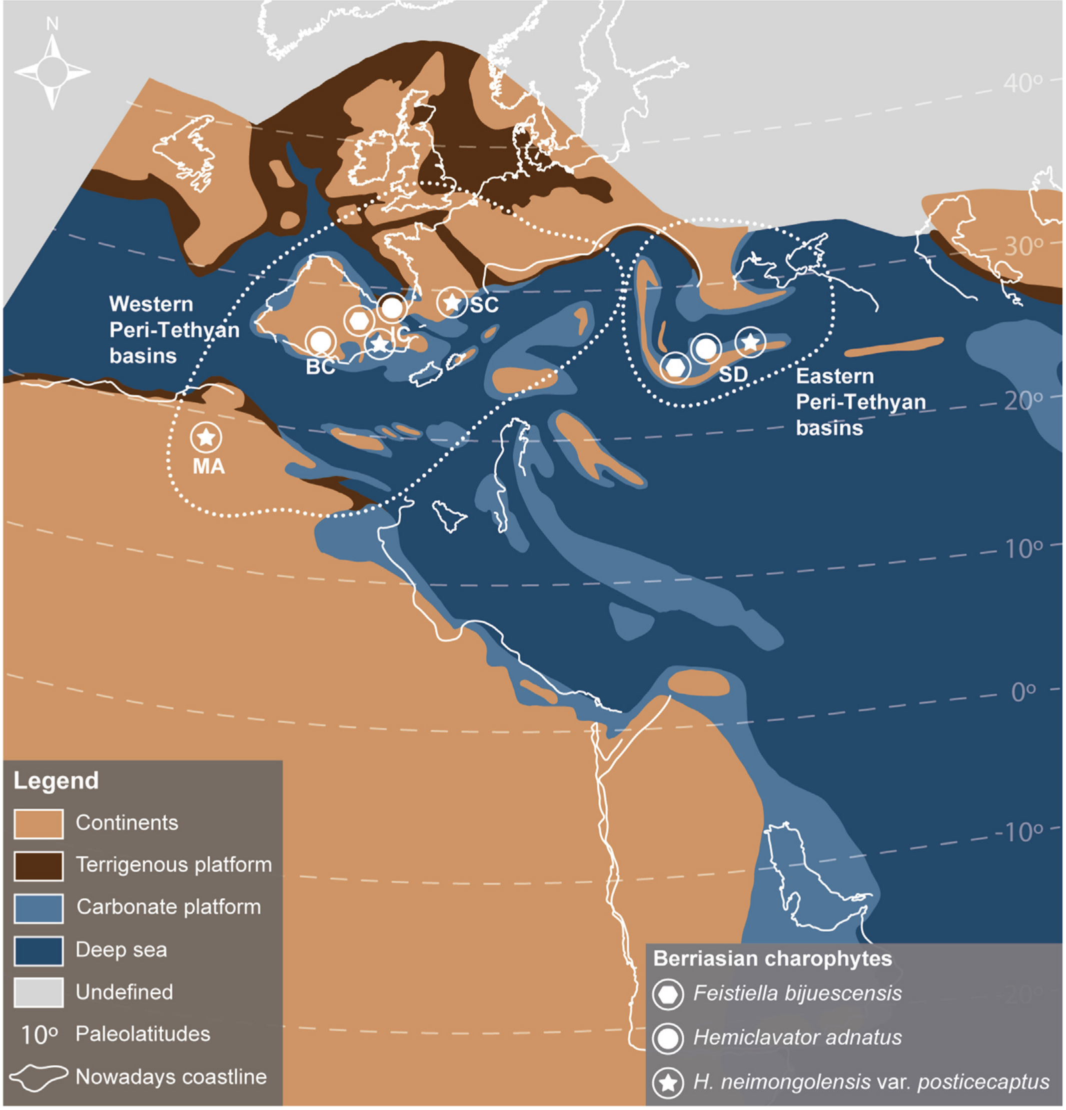

**Fig. 9.** Palaeogeographic map of the Tethys during the Berriasian, showing the distribution of the taxa, *Feistiella bijuescensis*, *Hemiclavator adnatus*, and *Hemiclavator neimongolensis* var. *posticecaptus*, reported for the first time in the eastern Tethyan archipelago. The dashed ellipse indicates the main areas from which these species were recovered. Capital letters represent the positions of the main localities where these species were found. Abbreviations: **SC**=Subalpine Chain (France), **IC**=Iberian Chain and Maestrat Basin (Spain), **BC**=Baetic Chain (Spain), **MA** = Moroccan Atlas (Morocco), and **SD**=South Dobrogea (south-eastern Romania). Palaeogeographic map modified from Dercourt et al. (1993).

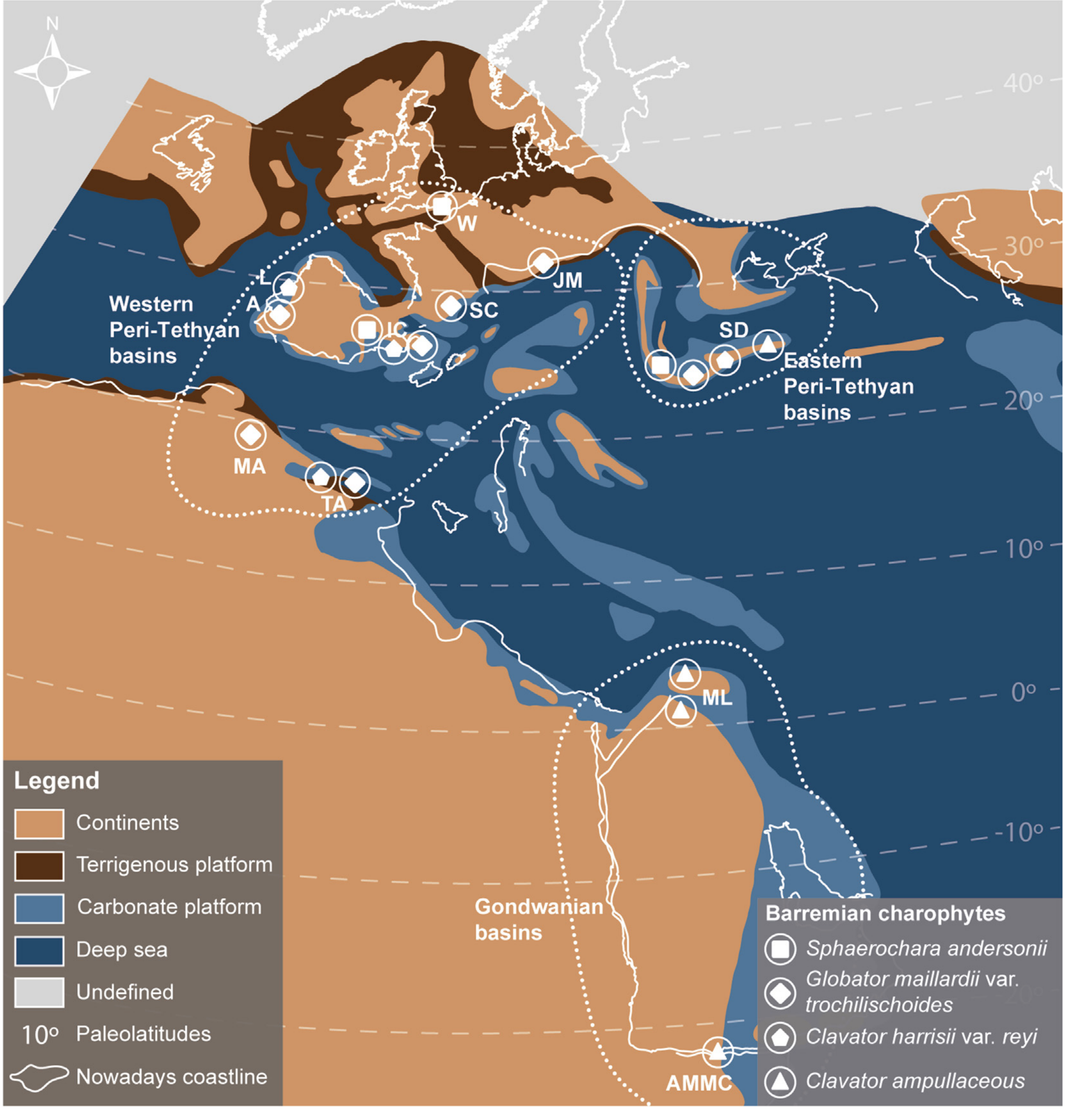

**Fig. 10.** Palaeogeographic map of the Tethys during the Barremian, showing the distribution of the taxa, *Sphaerochara andersonii*, *Globator maillardii* var. *trochiliscoides*, *Clavator harrisii* var. *reyi,* and *Clavator ampullaceus,* which have been reported for the first time in the eastern Tethyan archipelago. Dashed ellipses indicate the two main areas where these species thrived. Capital letters represent the positions of the main localities where these species were found. Abbreviations: **W** = Weald (UK), **JM** = Jura Mountains (Switzerland), **SC** = Subalpine Chain (France), **IC** = Iberian Chain and Maestrat Basin (Spain), **L** = Lusitanian Basin (Portugal), **A** = Algarve (Portugal), **MA** = Moroccan Atlas (Morocco), **TA** = Tunisian Atlas (Tunisia), **AMMC** = Al Mado mountain chain (Somalia), **ML** = Mount Lebanon (Lebanon and Israel), and **SD** = South Dobrogea (Romania). Palaeogeographic map of the Early Cretaceous, modified from Dercourt et al. (1993).

(Riveline et al., 1996). Additionally, one sample in Cernavodă POD provided utricles of *Globator maillardii* var. *nurrensis*, which is considered the index species of the homonymous European charophyte biozone Globator maillardii nurrensis, that indicates late Berriasian age (Riveline et al., 1996). Ostracod biostratigraphic data and the occurrence of *H. adnatus* and *H. neimongolensis* var. *posticecaptus* associated with *G. maillardii* var. *nurrensis* in one of the samples from Cernavodă suggest that the three species may be older in Romania than in western Europe. Alternatively, given the correlation of *G. maillardii* var. *nurrensis* with the ammonite biozonation in the Swiss Jura (Détraz and Mojon, 1989), the Zăvoaia Member at Cernavodă may have reached the late Berriasian.

b) Gherghina Formation: The charophyte assemblage recovered from this unit is dominated by the species *Atopochara trivolvis* var. *triquetra* and *Clavator grovesii* var. *jiuquanensis*. Less abundant species include *Sphaerochara andersonii*, aff. *Mesochara harrisii,* and *Clavator ampullaceus* var. *latibracteatus* var. nov., which occur in the drilling core F6 in Nazarcea, and *Globator maillardii* var. *trochiliscoides*, *Globator maillardii* var. *biutricularis,* and *Clavator harrisii* var. *reyi* in samples from Cernavodă (drilling boreholes FMAp5 and Ph3). This assemblage can be attributed to the European charophyte biozone, Ascidiella cruciata-Pseudoglobator paucibracteatus, of Martín-Closas et al. (2009), indicating that the relative age of the Gherghina Formation is late Barremian to early Aptian (Fig. 8). This age attribution is compatible with the relative ages previously assigned to the Gherghina Formation. According to Avram et al. (1993), this unit is Aptian in age, based on its stratigraphic position between the lower Aptian Ramadan Formation and the Albian Cochirleni Formation, and its palynomorph, ostracod and charophyte assemblages. The ostracod assemblage of the Gherghina Formation has recently been studied in detail by Antoniade (2016), who described four freshwater species, *Theriosynoecum fittoni* Mantell, 1844, *Cypridea* sp. 1. (possibly referring to *Cypridea recta recta*), *Cypridea* sp. 2 (possibly referring to *Cypridea fasciata*), and *Cypridea* sp. 3. The occurrence of *T. fittoni* is significant from the biostratigraphic viewpoint since it represents a characteristic taxon of the Weald Clay (England) associated with the Cypridea valdensis Zone (the last Wealdian ostracod zone of Anderson (1985)) which is Barremian in age. Horne (1995) also defined a homonymous biozone (Theriosynoecum fittoni Zone) for the Weald Clay (Wealden Group) of England. According to this author, the Theriosynoecum fittoni Zone displays a wide biostratigraphic range including the Hauterivian and the Barremian. However, the extension of the biostratigraphic range of this freshwater species in younger deposits (e.g., Aptian) cannot be excluded since in its type locality (Weald, England) fully marine facies cover the last occurrences of this species. Hence, younger biostratigraphic ranges may be detected elsewhere, such as in South Dobrogea.

### 5.2. Palaeobiogeography

The charophyte assemblage obtained from surface and subsurface sedimentary sequences in South Dobrogea (south-eastern Romania) sheds new light on the biogeographic distribution of charophytes in the Early Cretaceous Tethyan Archipelago and particularly in comparison with other palaeoislands of this palaeogeographic domain, i.e., the western area (nowadays western Europe and North Africa) and the southern margin of the Tethys (nowadays the Middle East and eastern Africa) (Figs 9 and 10).

The flora described in the Berriasian Zăvoaia Member comprises a total of 12 taxa, some of them already reported in South Dobrogea or nearby basins. This Berriasian assemblage displays a clear affinity with the flora of the western part of the Cretaceous Tethyan archipelago. The number of common species is even higher than previously thought, with the three additional species (*F. bijuescensis*, *H. adnatus,* and *H. neimongolensis* var. *posticecaptus*) now reported both in South Dobrogea (south-eastern Romania) and the western European region (Fig. 9). Very significantly, this is the first description in Europe of *C. bilateralis*, previously considered as endemic to North America. Although this species has previously been mentioned under the name of a younger synonym, *Clavator minutus,* in biostratigraphic studies from Pre-Dobrogea and South Dobrogea (Shaikin, 1976 and Avram et al., 1993, respectively), insufficient description and understanding of this species in its type locality in the United States, meant that these reports remained largely ignored. Recently, *C. bilateralis* has been re-defined and illustrated in the Western Interior Basin of North America by Martín-Closas et al. (2013), which allows confirmation of its occurrence in almost all samples studied within the Zăvoaia Member. This result points to an intercontinental distribution of *C. bilateralis* during the Berriasian, and to it thriving in distant basins at similar palaeolatitudes. Another species from the same studied assemblage, *C. grovesii* var. *grovesii*, had an even broader range during the Berriasian, from North America and Europe to China (Martín-Closas, 2015 and references therein). The absence of *C. bilateralis* in the Berriasian of western Europe is difficult to interpret but may be related to as yet unknown palaeoecological restrictions of this species.

The charophyte assemblage described within the Gherghina Formation is composed of nine species, four of which had previously been considered endemic to the western Barremian/Aptian Tethyan archipelago. These species are *S. andersonii*, *G. maillardii* var. *trochiliscoides*, *G. maillardii* var. *biutricularis,* and *C. harrisii* var. *reyi* (Fig. 10). In addition, the occurrence of *C. ampullaceus* in South Dobrogea is noteworthy (Fig. 10). This taxon was previously known exclusively from the Middle East (Mount Lebanon), by Grambast and Lorch (1968), and NE Africa (Al Mado mountain chain in northern Somalia), by Luger and Schudack (2001). Palaeogeographic reconstructions of the Mesogea during the Early Cretaceous place the regions of Lebanon and Somalia at much lower latitudes than at present, i.e., near the equator, while the northern islands of the Cretaceous Tethyan Archipelago were located at between 20° and 30° north latitude (Dercourt et al., 1993). Thus, latitude was apparently not a biogeographic barrier for *C. ampullaceus*. Biome reconstruction of the Mesogean Early Cretaceous by Scotese (2003) indicates that tropical conditions prevailed in the south-eastern Tethys (e.g., Lebanon and Somalia) and more subtropical but still hot and humid conditions in the north-eastern part of the Cretaceous Tethyan Archipelago (e.g., South Dobrogea), while the climate was drier in the western palaeoislands of the same archipelago (e.g., Iberia). This may explain why *C. bilateralis* does not occur in the Berriasian of western Europe.

## 6. Conclusions

Twenty charophyte species are described and illustrated from two Lower Cretaceous surface and subsurface continental units (the Zăvoaia Member of the Amara Formation and the Gherghina Formation) belonging to the South Dobrogea Basin (south-eastern Romania). This study revisits and clarifies the taxonomy of Lower Cretaceous Romanian charophytes provided by the pioneering studies of Neagu and Georgescu-Donos (1973), and Avram et al. (1993), with samples from the same basin, and provides new biostratigraphic and biogeographic data. Two charophyte assemblages are clearly distinguished in each of the two lithological units.

The assemblage found in the variegated interval of the Zăvoaia Member is composed of 12 taxa, including *Feistiella bijuescensis*, *Atopochara trivolvis* var. *micrandra,* aff. *Mesochara harrisii, Nodosoclavator bradleyi*, *Clavator bilateralis, Clavator grovesii* var. *grovesii,* and *Clavator grovesii* var. *discordis,* which can be attributed to the middle to late Berriasian. However, in some samples, the occurrence of *Globator maillardii* var. *nurrensis*, which is common in the upper Berriasian of western Europe and is well correlated with the ammonite biozonation, suggests that this unit may have reached younger ages than previously thought. A new species, *Mesochara dobrogeica* sp. nov., is described within the Zăvoaia Member (Amara Formation). Furthermore, the presence of *Hemiclavator adnatus* and *Hemiclavator neimongolensis* var. *posticecaptus,* associated with *Globator maillardii* var. *nurrensis* and with middle Berriasian ostracods suggests that these charophytes are older in Romania than in western Europe, where they occur first in the Valanginian. On the other hand, the charophyte assemblage recovered from the Gherghina Formation is composed of eight taxa dominated by *Atopochara trivolvis* var. *triquetra* and *Clavator grovesii* var. *jiuquanensis*. These species can be attributed to the Ascidiella cruciata-Pseudoglobator paucibracteatus European charophyte biozone (late Barremian to early Aptian). The suggested relative age of both continental rock units, based on charophyte assemblages, is only in partial agreement with the ages provided by previous biostratigraphic works performed in the area, based on ostracods.

This study gives new insights into the palaeogeographic distribution of Lower Cretaceous charophytes in the Cretaceous Tethyan Archipelago. Both the charophyte assemblages studied display strong affinities with the flora from the western part of the archipelago. However, the occurrence of the thus far exclusively North American taxon, *C. bilateralis,* in Romania suggests that this species had an intercontinental distribution despite not having been recorded in western Europe, which is probably due to palaeoecological factors. In addition, the occurrence of the north Gondwanian *C. ampullaceus* in Romania has been attributed to palaeoclimatic controls. Moreover, a new variety of this species, *C. ampullaceus* var. *latibracteatus* var. nov. is described herein. These new findings enhance the biostratigraphic value of these species for intercontinental biostratigraphic correlation.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cretres.2021.104762.