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A New Scallop Species, *Syncyclonema goyi* sp. nov. (Bivalvia, Pectinida, Entoliidae), from the Upper Cenomanian of West Portugal

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Abstract

A new species of pectinid bivalve, *Syncyclonema goyi* sp. nov., is described in honour of Professor Antonio Goy, one of the leading stratigraphers who shaped Mesozoic studies in Iberia over the past half century. It represents one of the smaller fossil scallops currently known from the Upper Cretaceous of Europe, alongside a few boreal species previously assigned to the family Entoliidae. The type specimens have orbicular valves, almost smooth, with unequal auricles. The right valve is more convex and bears a well-marked paleal sinus. The sculpture of the shell is weak, exhibiting concentric growth lines and lamellae. However, nearly 90 very small, uniform radial striae are discernible beneath the outer shell layer. This species is frequent in open marine, fine-grained, inner shelf facies of the Tethyan West Portuguese Carbonate Platform, near the main localities of Coimbra, Tentúgal, and Condeixa-a-Nova, in the Baixo Mondego region of West Portugal. It mostly occurs in the upper Cenomanian beds of the Trouxemil Formation, with *Euomphaloceras septemseriatum* and Vascoceratidae ammonites.

Keywords: Entoliidae; Pteriomorpha; taxonomy; palaeoecology; Cenomanian; Upper Cretaceous; West Iberia

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1. Introduction

Scallops are a widespread group of fossil and recent bivalve molluscs of the order Pectinida, recognised by their graceful disc-shaped valves ornated with auricles and radial ribs [1]. They are known through more than 400 extant species [2], and are distributed across a wide range of marine and paralic environments, including deep-water to inner shelf areas, reefs, and lagoons, where a diverse array of adaptations to substrate, salinity, and several other abiotic factors highlights a remarkable level of ecological adaptation.

The fossil record and taxonomic diversity of pectinids (order Pectinida) are even more significant when Cretaceous and Cenozoic strata are concerned [3]. Since their origin and early expansion in the Late Triassic, their diversification has resulted in the documentation of several tens of genera and many hundreds of species.

The European Cretaceous pectinids have been the focus of extensive research since the early 19th century. The systematics of the European boreal and temperate species was reviewed by Dhondt [4–9] (and references therein). Further data related to European taxa were also provided by Dhondt [10–16], Cleevely and Morris [17], Dhondt and Dieni [18–20], Malchus et al. [21], Smettan [22], Dhondt and Freneix [23], Morris et al. [24], Schneider et al. [25], Niebuhr et al. [26], and Kunstmüllerová and Košťák [27], among others. These studies highlight several remarkable differences between Boreal assemblages and those of the south European carbonate platforms, where the Pectinida exhibit close affinities with the Tethyan Realm during the Late Cretaceous.

The pectinid bivalves from the Upper Cretaceous of Portugal are mainly known from Cenomanian and lower Turonian mixed and carbonate facies, which are typical of shallow-water, inner shelf carbonate platform palaeoenvironments. Other occasional occurrences have been reported from upper Coniacian and upper Campanian marine units [28–31].

All these settings and their molluscan fossil assemblages have been documented through a plethora of palaeontological and stratigraphic works such as Sharpe [32–34], Choffat [28,35–40], Costa [41,42], Moura [43], Soares [44–49], Berthou et al. [50,51], Amédro et al. [52], Callapez [53–55], Savazzi [56], Barroso-Barcenilla et al. [57–60], and Ozkaya de Juanas et al. [61].

As a result, there are numerous available data complemented by reference collections housed in the museum of the National Laboratory of Energy and Geology (LNEG; former Geological Survey of Portugal) and the Natural History museums of the universities of Coimbra and Lisbon. These collections yield many species of scallops distributed by the families Neitheidae, Pectinidae, and Entoliidae, with a higher diversity for the genus *Neithea*, including large specimens adapted to high-energy environments where they are associated with rudists.

The upper Cenomanian carbonate facies mentioned above record the peak of diversity for these assemblages [28,45]. Perhaps due to their minute size and fragility, Entoliidae fossils have been subject to less attention. Consequently, to fill this knowledge gap, our current field research and sampling in the Upper Cretaceous units of the Lusitanian Basin focused on these marine bivalves.

This study is concerned with the taxonomical description of a new species of *Syncyclonema*, a small scallop found in upper Cenomanian carbonate platform facies of West Portugal (Figure 1a–c). In addition to morphological assessments and comparisons with other Upper Cretaceous Entoliidae representatives, the biostratigraphical range and the palaeoecological setting of the new species are emphasised, considering the Tethyan carbonate platform context where it was discovered.

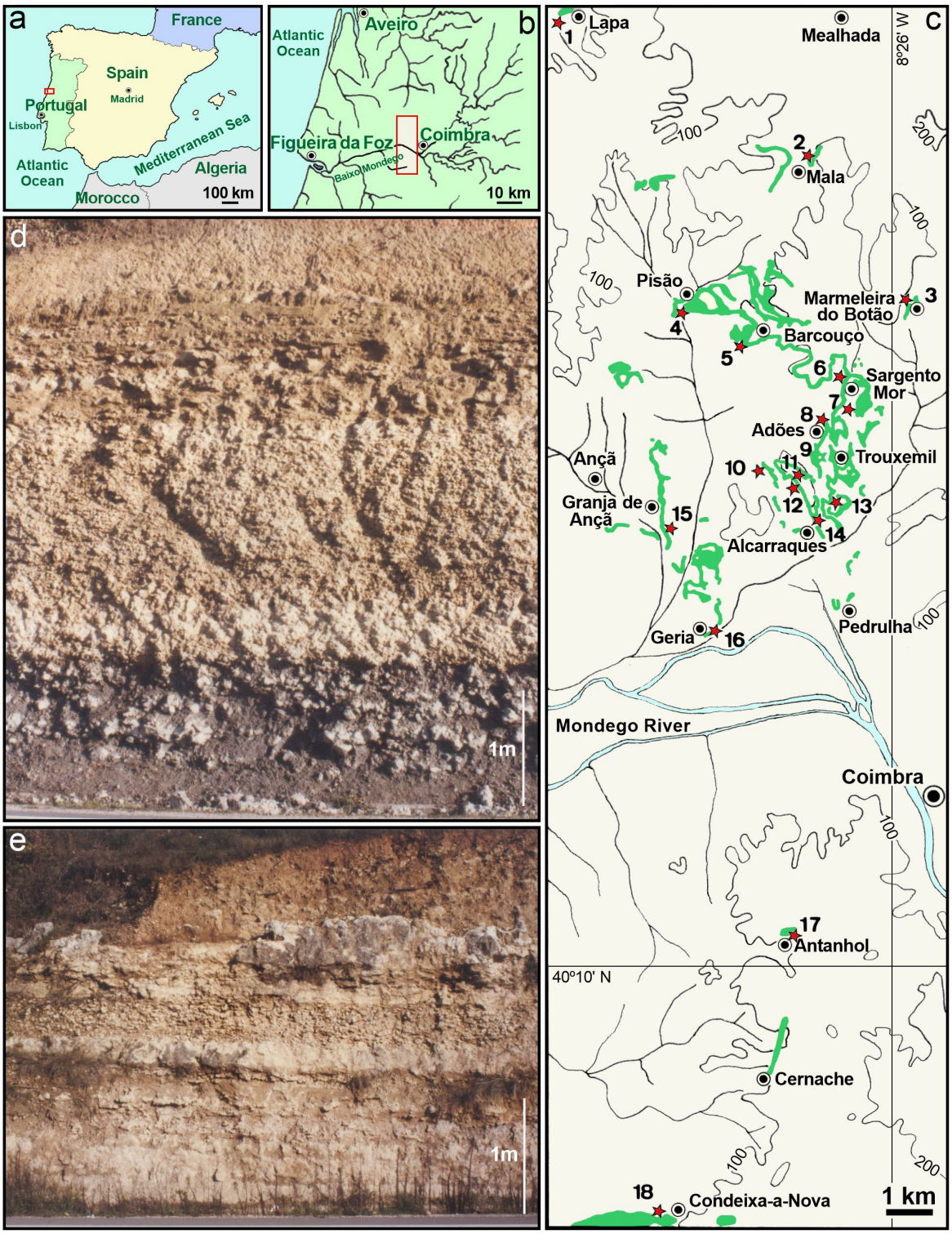

Figure 1. Location and geological context of the studied area. (**a**)—General location in the Iberian Peninsula (red box). (**b**)—Location in the Baixo Mondego region of West Portugal (red box). (**c**)—Overview of the studied area in the eastern ranges of Baixo Mondego, showing the main localities (black circles) and the geological mapping of the Cenomanian–Turonian Trouxemil Fm. (green areas), with indication of the stratigraphic sections with carbonate and mixed facies with *Syncyclonema goyi* sp. nov. (red stars). 1—Lapa, 2—Mala, 3—Marmeleira do Botão, 4—Pisão, 5—Barcouço, 6—Sargento-Mor, 7—Salgueirosa (Trouxemil), 8—Adões, 9—Senhora das Neves, 10—Rios Frios, 11—Quinta do Belregão, 12—Espigão 1, 13—Cioga do Monte, 14—Espigão 2,

15—Fonte da Areia (Ançã), 16—Geria, 17—Antanhol, 18—Condeixa-a-Nova. (**d**)—Upper member of the Trouxemil Fm. (upper Cenomanian units with facies of nodular marly limestone) in the section of Fonte da Areia (Ançã), the type locality of *Syncyclonema goyi* sp. nov. (**e**)—Lower part of the same section (basal upper Cenomanian units with facies of sandy marl and nodular marly limestones and massive whitish limestone).

2. Geographical and Geological Setting

The Cenomanian stage is well-documented in West Portugal as a part of the Albian–Turonian sedimentary record of the West Portuguese Carbonate Platform (WPCP) [31,62–66]. The development of this Tethyan carbonate platform in the West Iberian continental margin occurred during a time of high eustatic sea level, when large areas of Southern Europe were submerged by shallow seas [67–73].

The carbonate and mixed carbonate–siliciclastic sequences of the WPCP are the largest marine sedimentary units found in the thick Aptian–Maastrichtian post-rift sedimentary cover of the Lusitanian Basin [74–78]. This marginal Atlantic basin was predominantly active during the Late Triassic, Jurassic, and Early Cretaceous rifting episodes, all of which are extensively recorded in the stratigraphic successions of the onshore regions of Portuguese Estremadura and Beira Litoral [30,79–94]. In these same areas, and between Lisbon, Coimbra, Figueira da Foz, and Aveiro, the Cenomanian of the WPCP is extensively exposed, always with highly fossiliferous carbonate facies, including a large abundance and diversity of Bivalvia [95–98].

During the late Cenomanian, the WPCP reached its maximum extent onshore, and large rimmed inner-platform domains with coral and rudist buildups developed between Lisbon, Nazaré, and Leiria [28,31,35,62–64]. To the north, these domains were replaced by open shelf areas with cephalopods, whose associations, rich in representatives of Acanthoceratidae and Vascoceratidae, allow for accurate biostratigraphical precision, with emphasis on the Iberian and North African Tethyan basins [99–101]. These data are complemented by the occurrence of several taxa of planktic foraminifera (e.g., *Heterohelix* sp. cf. *H. moremani*, *Guembelitria cretacea*, *Hedbergella delrioensis*, *Whiteinella* spp., and *Helvetoglobotruncana praehelvetica*), together with abundant shallow-water benthic taxa, including miliolids, orbitolinids, and alveolinids [102]. Among them, the species *Hemicyclammina sigali*, *Simplalveolina simplex*, and *Thomasinella punica* stand out as typical of many mid-Upper Cenomanian successions from inner to middle shelf carbonate platform environments [31,63,102].

The most complete and thickest upper Cenomanian open shelf non-rudist succession of the WPCP is exposed near the coastal town of Figueira da Foz, where it comprises sequences of limestone and marly limestone beds, currently named as beds "C" to "J" of the Costa d'Arnes Formation (Fm.), and representative of middle shelf palaeoenvironments with ammonites and abundant benthic assemblages of bivalves, gastropods, and echinoids [28,31,37,45,49,54,103–111]. With a maximum thickness of 30 m, these beds reveal significant lateral continuity and can be correlated with many other exposures located to the east in the Baixo Mondego region, between the localities of Granja de Ançã, Trouxemil, Barcouço, Coimbra and Condeixa-a-Nova [28,31,45,49,53,110,112,113] (Figure 1d,e).

Near these locations, the upper Cenomanian WPCP lithostratigraphy comprises the Tentúgal Fm. [114] and the Trouxemil Fm. [115], both characterised by successions with facies of marly nodular limestone and massive limestone (beds "C" and "D"), overlaid by beds of laminated marls and sandy marls with limestone nodules, and interbedded nodular marly limestones (beds "E" to "J") [28,45,49,110,116]. These sequences are transgressive over a thick unit of post-rift coarse alluvial siliciclastics, known as "Lower Coarse Sandstone" [45,49] or the Grada–Barcouço Fm. [115]. The carbonate facies associations record inner shelf, lagoonal, and tidal flat domains where fossil assemblages of bivalves,

gastropods, echinoids, and other benthic invertebrate groups, alongside aquatic vertebrates, stand out as remarkable ecostratigraphic and paleoenvironmental indicators for the local shallow and marginal marine domains of the carbonate platform [45,48,49,55,117–119].

The occurrence of scallop bivalves, including the new species *Syncyclonema goyi*, is higher in these upper Cenomanian inner domains of the WPCP, with *Vascoceras gamai* and other related species of Tethyan ammonites. The stratigraphic succession is representative of the *Euomphaloceras septemseriatum* and *Pseudaspidoceras pseudonodosoides* biozones, which partly correlate with the standard biozones of *Metoicoceras geslinianum* and *Neocardioceras juddii* [54,120–122]. The studied specimens were collected from several localities of these inner domains, with emphasis on Fonte da Areia, the type locality (Figure 2), and Condeixa-a-Nova, where the new species is locally abundant in marly levels with *E. septemseriatum* and the foraminifera *Thomasinella punica* and *Hemicyclammina sigali* and rare *Heterohelix* sp. and *Hedbergella* sp. [31,102].

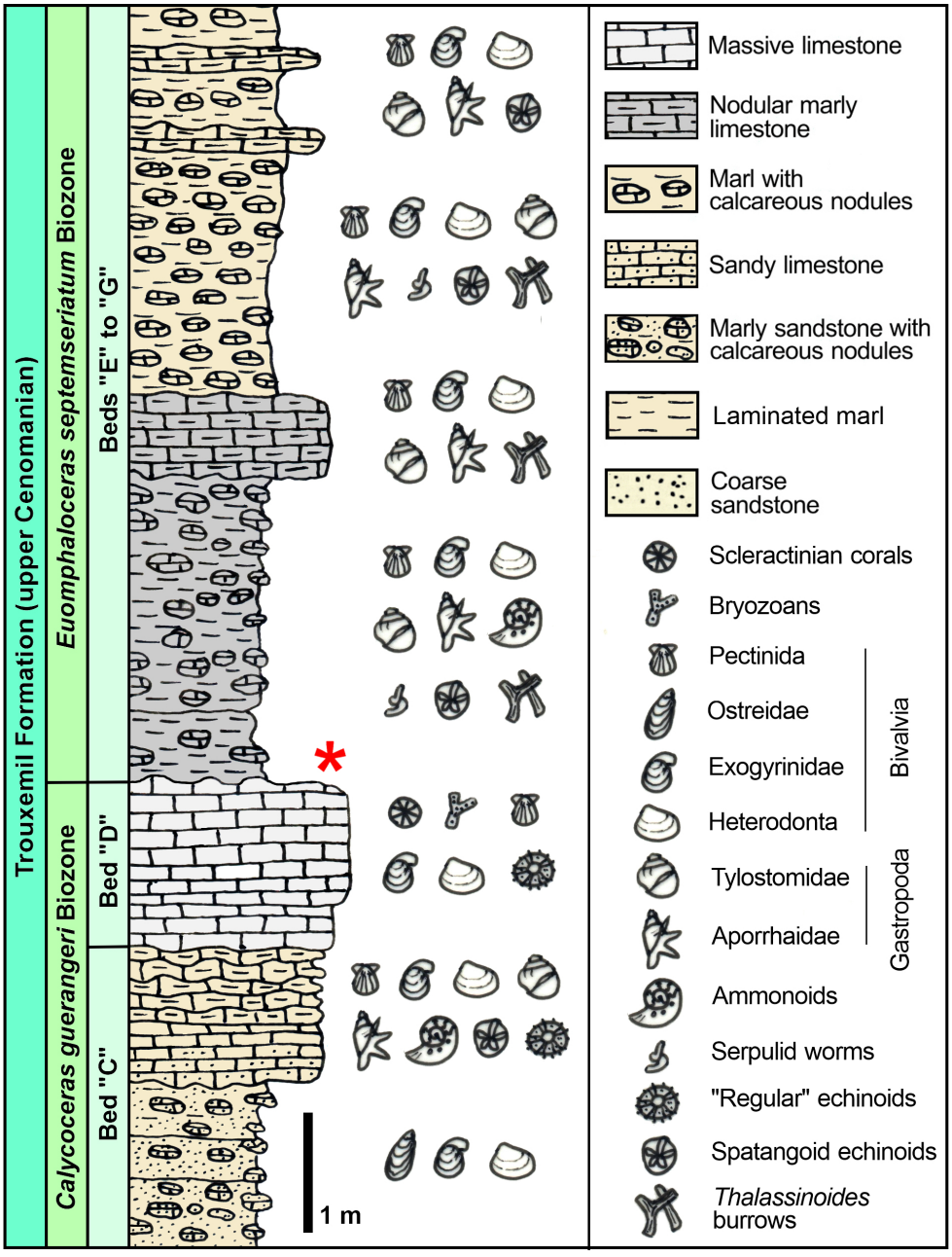

Figure 2. Stratigraphic section of Fonte da Areia, Ançã (West Portugal), the type locality for *Syncyclonema goyi* sp. nov., showing the upper Cenomanian inner shelf units of the Trouxemil Fm., comprising

carbonate and mixed carbonate–siliciclastic facies rich in invertebrate assemblages. The red asterisk marks the stratigraphic position of the holotype of *Syncyclonema goyi* sp. nov. described herein.

3. Materials and Methods

The studied sample comprises 83 specimens collected from eight exposures with upper Cenomanian beds of the WPCP, and situated between the Trouxemil, Coimbra, and Condeixa-a-Nova localities. All of them are disarticulated valves sampled bed by bed during stratigraphical fieldwork. Their accurate position in the local sections is known, as well as their biostratigraphical setting based on cephalopod assemblage zones.

All specimens were carefully cleaned, numbered with China ink covered by nail varnish, and prepared either manually or mechanically with an electric vibro-tool, at laboratory facilities of the Earth Sciences Department, University of Coimbra. Since the valves of *Syncyclonema* are thin and fragile, and most specimens are preserved in marly matrix, a dry cleaning was preferred instead of the use of liquids.

A Nikon SMZ800 binocular microscope (Nikon Corporation, Nishioi, Shinagawa-ku, 140-8601 Tokyo, Japan) with a magnification range of 10×–63× was used to observe microstructural details relevant for the taxonomic descriptions. All specimens for morphological description were documented with labels and photographed using a digital camera Olympus© E-M5II (Olympus Corporation, Ishikawa-machi, Hachioji-shi, 192-8507 Tokyo, Japan) at the University of Alcalá (Spain).

As a repository of specimens, the collection has been housed at the Earth Sciences Department, University of Coimbra, Coimbra, Portugal, and is fully available to the scientific community. The new species here described was also recorded under the ZooBank reference: LSID: urn:lsid:zoobank.org:act: 2DF6774F-C712-49C1-8C2F-37BC66B9F182.

4. Systematic Palaeontology (by P. M. Callapez, F. Barroso-Barcenilla, M. Berrocal-Casero, and R. J. Pimentel)

For the systematic above the taxonomic rank of species, the works of Bieler et al. [123–125], Huber [126,127], and Carter et al. [128] have been considered, besides the WoRMS [129] database and additional contributions by Newell [130], Moore [131], and Waller [132,133]. The morphological terms follow the terminology adopted by Moore [131] and Dhondt [4]. The following abbreviations have been used: DCTUC—Earth Sciences Department of the University of Coimbra; UA—umbonal angle; LV—left valve; L—length; RV—right valve; UPD—umbo paleal diameter (or height); W—width.

Class: Bivalvia Linnaeus, 1758 [134].

Subclass: Pteriomorphia Beurlen, 1944 [135].

Order Pectinida Gray, 1854 [136].

Superfamily: Entolioidea von Teppner, 1922 [137].

Family: Entoliidae von Teppner, 1922 [138].

Subfamily: Syncyclonematinae Waller, 1978 [132].

Genus: *Syncyclonema* Meek, 1864 [138].

Type-species: *Pecten rigida* Hall et Meek, 1856 [139] (= non Sowerby, 1818 [140]; = *Pecten halli* Gabb, 1861 [141]) by original designation [142].

Species: *Syncyclonema goyi* sp. nov. (Figures 3 and 4)

Type material: The type specimens designated here, consist of the holotype and 20 paratypes, all of them disarticulated valves.

Holotype: LV (DCTUC-FA8-BR100), from Fonte da Areia, Ançã, West Portugal (upper Cenomanian; units E/G of Trouxemil Fm.) (Figure 3a–d).

Paratypes: RV (DCTUC-FA9-BR54) from Fonte da Areia, Ançã, West Portugal (upper Cenomanian; units E/G of Trouxemil Fm.) (Figure 3e,f); 2 RV (DCTUC-CX16, DCTUC-CX34) from Condeixa-a-Nova, West Portugal (upper Cenomanian; units E/G of Trouxemil Fm.) (Figure 3g–j); 3 LV (DCTUC-CX40, DCTUC-CX14, DCTUC-CX20) and 2 RV (DCTUC-CX22, DCTUC-CX37) from Condeixa-a-Nova, West Portugal (upper Cenomanian; units E/G of Trouxemil Fm.) (Figure 4a,b,i,k,l); RV (5062) from Espigão 2 (upper Cenomanian; unit D of Trouxemil Fm.) (Figure 4c); 4 LV (DCTUC-QB48-BR106, DCTUC-QB48-BR107, DCTUC-QB55-BR113, DCTUC-QB55-BR109) and 2 RV (DCTUC-QB55-BR108, DCTUC-QB55-BR110a-b) from Quinta do Belregão, Trouxemil, West Portugal (upper Cenomanian; units H/J of Trouxemil Fm.) (Figure 4d,e,g,n–p); RV (DCTUC-RF7) from Rios Frios, West Portugal (upper Cenomanian; units E/F of Trouxemil Fm.) (Figure 3f); 2 LV (DCTUC-E34-BR112, DCTUC-E34-BR111) from Espigão, Alcarraques, West Portugal (upper Cenomanian; units H/J of Trouxemil Fm.) (Figure 4h,m); RV (DCTUC-A8-BR53) from Antanhol, West Portugal (basal upper Cenomanian; unit C of Trouxemil Fm.) (Figure 4j).

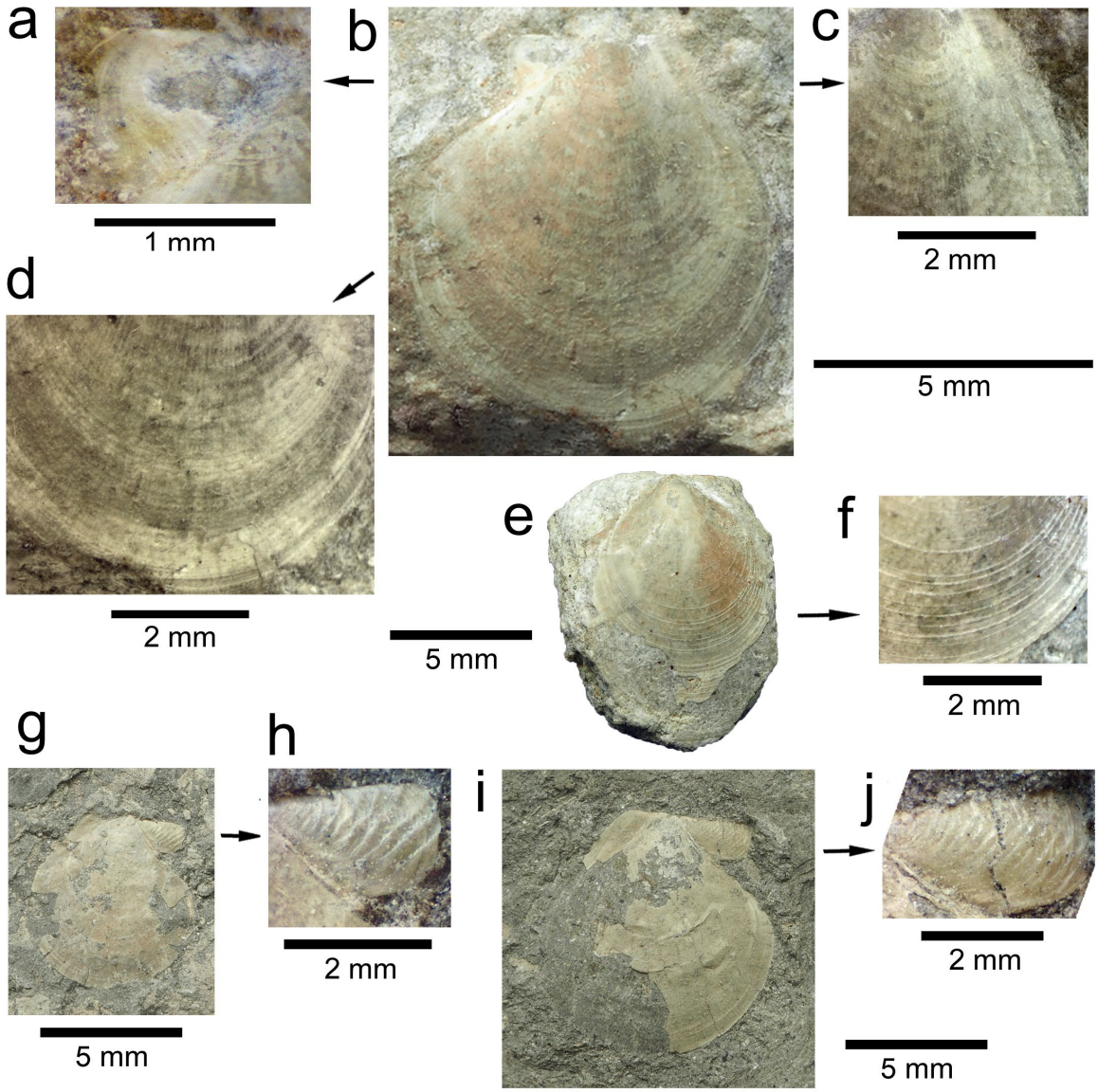

Figure 3. *Syncyclonema goyi* sp. nov. (Callapez, Barroso-Barcenilla, Berrocal-Casero, and Pimentel) from the upper Cenomanian of West Portugal. (**a**–**d**) Holotype, left valve, with the shell layers and internal microstructure preserved, (**a**) detail of the anterior auricle, (**b**) general view, (**c**) detail of the posterior auricle, (**d**) detail of the sculpture with nearly 90 very small, uniform radial striae; DCTUC-FA8-BR100. (**e**,**f**) Paratype, right valve, with the shell layers and internal microstructure

partly preserved, (**e**) general view, (**f**) detail of the sculpture in the ventral side of the disc; DCTUC-FA9-BR54. (**g**,**h**) Paratype, right valve, with the shell compressed and recrystallized, (**g**) general view, (**h**) detail of the anterior auricle; DCTUC-CX16. (**i**,**j**) Paratype, right valve, with internal mould and the shell compressed and recrystallized, (**i**) general view, (**f**) detail of the anterior auricle; DCTUC-CX34. Localities: (**a**–**f**) Fonte da Areia, Ançã; (**g**–**j**) Condeixa-a-Nova.

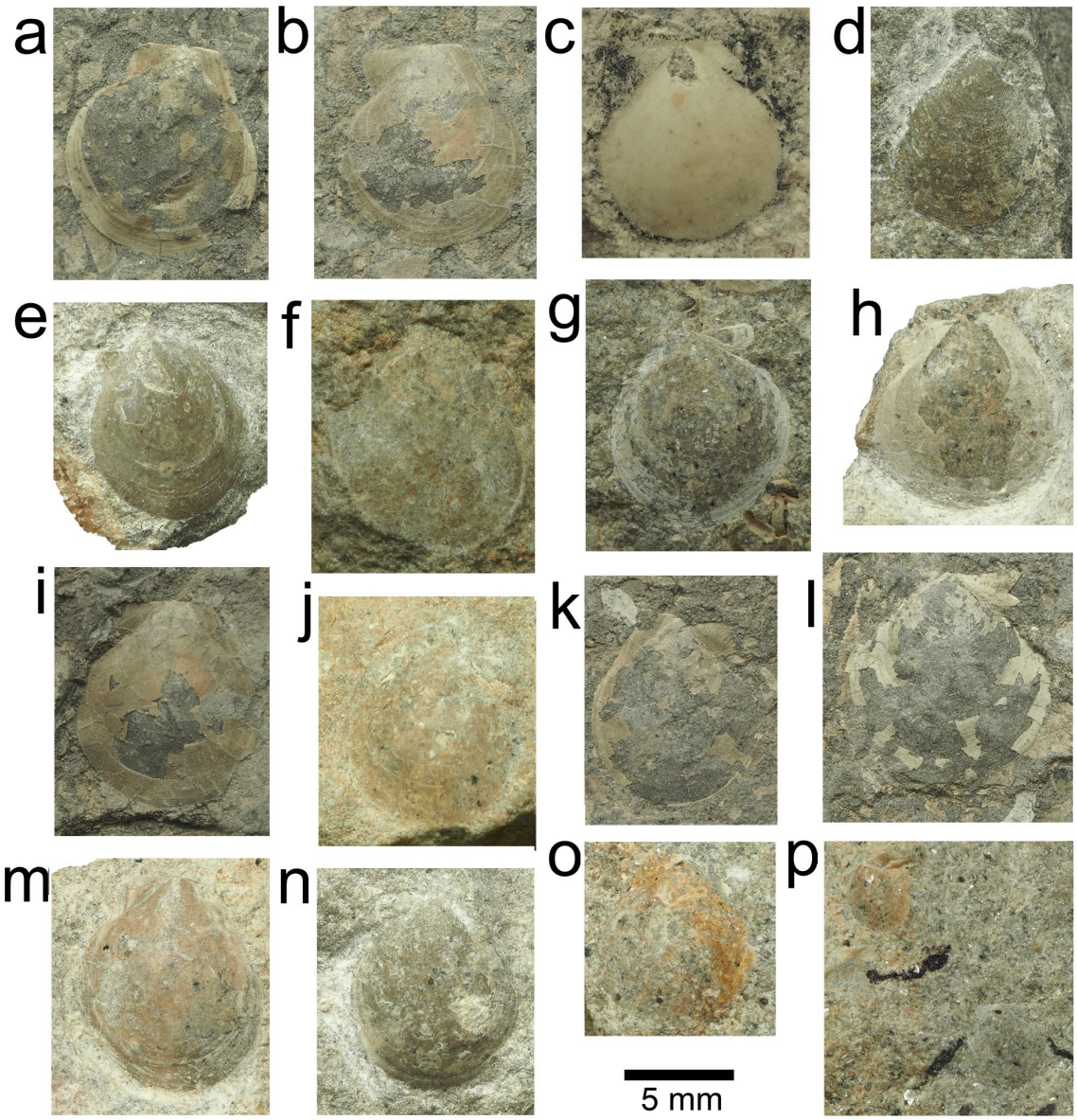

Figure 4. Paratypes of *Syncyclonema goyi* sp. nov. (Callapez, Barroso-Barcenilla, Berrocal-Casero, and Pimentel) from the upper Cenomanian of West Portugal. (**a**) Left valve (LV); DCTUC-CX40. (**b**) LV; DCTUC-CX14. (**c**) Right valve (RV); 5062. (**d**) LV; DCTUC-QB48-BR106. (**e**) LV; DCTUC-QB48-BR107. (**f**) RV; DCTUC-RF7. (**g**) RV; DCTUC-QB55-BR108. (**h**) LV; DCTUC-E34-BR112. (**i**) LV; DCTUC-CX20. (**j**) RV; DCTUC-A8-BR53. (**k**) RV; DCTUC-CX22. (**l**) RV; DCTUC-CX37. (**m**) LV; DCTUC-E34-BR111. (**n**) LV; DCTUC-QB55-BR113. (**o**) LV; DCTUC-QB55-BR109. (**p**) RV; DCTUC-QB55-BR110a-b. Localities: (**a**,**b**) Condeixa-a-Nova; (**c**) Espigão 2; (**d**,**e**) Quinta do Belregão; (**f**) Rios Frios; (**g**) Quinta do Belregão; (**h**) Espigão; (**i**) Condeixa-a-Nova; (**j**) Antanhol; (**k**,**l**) Condeixa-a-Nova; (**m**) Espigão; (**n**–**p**) Quinta do Belregão.

Additional studied specimens: A total of 65 valves, of which 29 LV and 30 RV are from the stratigraphic sections of Condeixa-a-Nova, West Portugal (upper Cenomanian; units E/G of Trouxemil Fm.), one RV from Lapa, Cantanhede, West Portugal (upper Cenomanian;

units E/I of Trouxemil Fm.), three RV from Espigão, Alcarraques, West Portugal (upper Cenomanian; units H/J of Trouxemil Fm.), and two RV from Quinta do Belregão, Trouxemil, West Portugal (upper Cenomanian; units H/J of Trouxemil Fm.).

4.1. Generic Diagnosis

The emended diagnosis proposed by Speden [142] and expanded by Dhondt [4] to include medium-sized species, is adopted here:

"Small [to medium sized], subequivalve, subequilateral. Shell of vitreous appearance, thin, of three layers: thin outer homogeneous or prismatic layer, middle layer of zigzag lamellar structure, and thin inner complex cross-lamellar layer. Ornament sub-macroscopic, except on ears, of fine non-punctate diverging radial striae, fine growth striae, and coarser irregular growth lamellae tending to give reticulate pattern. Radial striae strongest at ventral margin and on dorsal flanks of disc of shell, sometimes absent on centre of disc. Concentric lamellae strong on ears. Interior of shell sometimes with low faint rounded concentric ridges and fine radial striae. Concentric undulations sometimes evident on external surface, particularly on the right valve. Anterior auricle equal to or significantly larger than the posterior.

Anterior auricle of the right valve distinctly separated from disc of shell, fasciole very narrow, and byssal sinus deep, open V-shaped. No ctenolium. Dorsal margin of right valve overlaps that of the left valve. Each auricle with one thin cardinal crus below the ligament band, that on the posterior auricle of each valve extending usually only about two-thirds of the distance towards the posterior margin. One relatively long strong tooth-like process on either side of the resilifer pit of the right valve. No auricular crura. Adductor muscle impression small, subcircular, sited above two thirds the height of shell adjacent to basal part of posterior auricle. Pallial line continuous" [142].

4.2. Derivatio Nominis

The new species is named in honour of Antonio Goy, Emeritus Professor of the Complutense University of Madrid, one of the leading stratigraphers who shaped Mesozoic studies in Iberia over the past half century.

4.3. Type Locality

Fonte da Areia, Ançã, West Portugal (40°15′22″ N; 8°29′59″ W) (Figure 1d,e).

4.4. Type Horizon

Middle upper Cenomanian (Trouxemil Fm., West Coimbra, West Portugal).

4.5. Diagnosis

Small *Syncyclonema* species with a thin, fragile shell, with orbicular shape. Slightly convex valves, rounded, with moderately asymmetrical discs and rather small, unequal auricles. Hinge straight, normal to the dorso-ventral axis, with a length of about two-thirds of the disc. Auricles unequal. RV bears a long anterior auricle with rounded outline, separated from the disc by a deep byssal notch; the posterior auricle is subtriangular shaped, obtuse-angled, and curved at the extremity of the dorsal hinge-line, with a height close to 30% of UPD. LV anterior auricle almost twice the size of the posterior, slightly acute-angled and rounded at the dorsal end corner; the opposite auricle is similar to the posterior auricle of RV. Sculpture very week, with numerous concentric growth lines over the disc and auricles, regularly and closely spaced, being more marked and lamellose along the ventral sides of the valves. Anterior auricles with lamellae in some specimens. Radial ornament sub-macroscopic, consisting of about 90 fine striae, closely spaced, diverging towards the lateral and ventral edges of the valves (Table 1).

Table 1. Dimensions of the holotype and paratypes (mm).

Specimen	UPD	L	W	AA
LV—Holotype (DCTUC-FA8-BR100)	7.8	6.9	1.2	104°
RV—Paratype (DCTUC-QB48-BR108)	8.8	-	1.4	102°
RV—Paratype (DCTUC-CX16)	6.2	5.9	-	101°
RV—Paratype (DCTUC-CX34)	8.3	8.4	-	97°
LV—Paratype (DCTUC--CX40)	9.6	9.0	-	101°
LV—Paratype (DCTUC- CX14)	9.4	8.6	-	90°
RV—Paratype (5062)	9.2	8.5	1.2	93°
LV—Paratype (DCTUC- QB48-BR106)	8.4	-	1.3	-
LV—Paratype (DCTUC- QB48-BR107)	8.4	7.4	1.4	90°
RV—Paratype (DCTUC-RF7)	9.6	8.8	-	97°
RV—Paratype (DCTUC- QB55-BR108)	8.9	8.3	1.5	108°
LV—Paratype (DCTUC- E34-BR112)	9.1	8.9	1.4	96°
LV—Paratype (DCTUC-CX20)	9.6	8.6	-	96°
RV—Paratype (DCTUC- A8-BR53)	8.4	8.3	1.0	94°
RV—Paratype (DCTUC-CX22)	9.1	8.0	-	94°
RV—Paratype (DCTUC-CX37)	10.0	9.6	-	99°
LV—Paratype (DCTUC- E34-BR111)	10.0	8.6	1.5	96°
LV—Paratype (DCTUC- QB55-BR113)	8.8	7.9	1.4	91°
LV—Paratype (DCTUC- QB55-BR109)	7.9	7.4	0.7	92°
RV—Paratype (DCTUC- QB55-BR110b)	4.3	3.8	0.4	97°

4.6. Geographical and Stratigraphic Distribution

The genus *Syncyclonema* Meek, 1864 is restricted to the Cretaceous Period and found in the United States of America and Europe. In the European basins, it is known from the Aptian to Maastrichtian [4].

The new species occurs in the Baixo Mondego region near Coimbra, in West Central Portugal. It was reported from the localities of Trouxemil, Adões and Sargento-Mor, near Coimbra, and Fonte da Areia (Ançã), Antanhol and Condeixa-a-Nova, in upper Cenomanian beds of the WPCP with carbonate and mixed facies, interpreted as the inner shelf domains of the carbonate platform (Trouxemil Fm.). It is especially abundant in the locality of Condeixa-a-Nova, where a fossil-rich succession of marly strata correlative of the *Euomphaloceras septemseriatum* ammonite biozone occurs. The whole stratigraphical distribution presently known ranges from the basal upper Cenomanian (*Calycoceras guerangeri* biozone), where the species is uncommon, to the uppermost part of this stage (*Pseudaspidoceras pseudonodosoides* biozone).

4.7. Discussion

The type specimens and the supplementary studied materials show all the morphological characteristics attributed to the genus *Syncyclonema* Meek, 1864, as redescribed by Speden [142] and adopted by Dhondt [4] and subsequent work. In addition to the size and shape of their discs and asymmetrical auricles, they are characterised by an RV with a well-developed byssal notch in the anterior auricle, which is absent in the opposite valve. Besides a fine sculpture with spaced concentric growth lines and lamellae, there is also a micro-ornamentation present on the middle shell layer, consisting of profuse and divergent

radial striae. They are only visible under magnification in valves with the three layers of the shell preserved, with particular emphasis on the holotype, giving some of the vermiculate *Camptonectes*-like appearance mentioned by Dhondt [4].

Although not uncommon in the studied area, being only locally abundant in the exposures of Condeixa-a-Nova, and mostly in the upper beds of the Trouxemil Fm., this small scallop species remained unknown in the research developed in the Cenomanian carbonate formations previous to 1992 [53]. The possible reason is the consequence of its small size and the poor preservation conditions of most specimens. The first valves found were tentatively classified as *Syncyclonema ?simplicia* by Callapez and Soares [143] in the absence of more diagnostic material.

Dhondt [4] reviewed in detail the various representatives of the genus in the Temperate-Boreal realm, including three small *Syncyclonema* species comparable to the new Portuguese one: *S. greppini* (Aptian–Albian), *S. gamsensis* (Santonian–Maastrichtian), and *S. haggi* (Turonian–Maastrichtian). However, they have different ages and biogeographic ranges compared to the Portuguese specimens. Their size is also comparatively larger and they differ in the number and shape of their radial striae, as well as in the RV and LV auricles.

Syncyclonema goyi sp. nov. also resembles some Upper Cretaceous species from central and southern areas of the Western Interior of the United States, in North America, such as *S. halli* (Campanian–Maastrichtian), *S. inconspicua* (Albian), and especially *S. simplicia* (Santonian–Maastrichtian). However, differences in auricle size and shape, as well as the number of striae, also persist, which enable the distinction of *S. goyi* sp. nov. from the previously mentioned species.

5. Range and Palaeoenvironment

The occurrence of Cretaceous *Syncyclonema* has been described from a wide variety of marine facies ranging from inner to outer shelf environments, with many species adapted to shallow water, carbonated, or mixed carbonate–siliciclastic, soft substrates, besides others known from deeper, more distal basin settings [144–147]. Most taxa have been found in North America, e.g., [142,148–151], Northwest and Central Europe, and former USSR, e.g., [4,14,21,152,153], suggesting short- to long-range dispersals within the Temperate-Boreal realm. These biogeographical patterns can be interpreted as adaptations to colder aquatic palaeoenvironments, ecologically diverse from the contemporary lower-latitude neritic assemblages of the Tethyan Realm containing Pectinida representatives.

Compared to these contexts, the occurrence of *Syncyclonema goyi* sp. nov. in upper Cenomanian beds of the WPCP stands out, as it confirms the data of Dhondt [12] for Spain, that this group of Entoliidae also existed in the Tethyan areas of Southern Europe with non-rudist, carbonate platform environments, where the sub-tropical conditions of this vast biogeographic realm prevailed during the high sea-level intervals of the Late Cretaceous [67–69,154].

The studied area where the new species occurs corresponds to the proximal domains of the WPCP in the Baixo Mondego region of West Portugal, between Figueira da Foz and Coimbra [30,54,55,110,155]. These are characterised by several upper Cenomanian fossil-rich inner shelf, lagoonal, and tidal flat domains with carbonate and mixed carbonate–siliciclastic facies yielding shallow-water invertebrate assemblages, where Tethyan molluscs such as *Neithea dutrugei*, *N. hispanica*, *Costagyra olisiponensis*, *Ceratostreon flabellatum*, *Tylostoma ovatum*, *T. torrubiae*, and *Ampullina puctata* are among the most widespread faunal elements [45,49,53].

The occurrence of *Syncyclonema goyi* sp. nov. in this setting, as well as the lithofacies and the invertebrate assemblages associated with the sampled specimens, seems to indicate that this small scallop species preferred shallow-water, infralittoral environments with

soft and oxygenated substrates located within the photic zone. However, it was absent from intertidal and lagoonal settings. Like many recent Pectinida with smooth and thin valves, and unequal auricles with a well-developed byssal notch, this minute Cretaceous scallop was a typical suspension-feeder that lived attached by a bissus to hard parts of the substrate, including living as an epizoan to other shells or macroalgae available in the local environment [156–160].

The species should also have been rather tolerant of substrate composition, as we found specimens in a variety of lithofacies, ranging from limestone and marly limestone to sandy limestone, micaceous sandstone, and marl. Among these, the carbonate lithofacies generally correspond to wackstone–packstone biomicrites rich in invertebrate microremains, benthic foraminifera, and dasicladacean algae [31,45,49,62,161].

However, *Syncyclonema goyi* sp. nov appears to be more abundant in the following depositional settings:

(a) Shallow infralittoral facies of micaceous, yellowish sandy limestones interbedded with fine-grained micaceous sandstones. These beds are characterised by the abondance of small tubes of serpulid worms, together with *Rhynchostreon*, small infaunal bivalves (e.g., *Nuculana*), gastropods (e.g., *Aporrhais*), and undetermined Decapoda claws. These invertebrates are part of a low-diversity faunal assemblage dominated by epifaunal suspension feeders (Figure 5), described as the "*Syncyclonema ?simplicia* and *Serpula*" fossil-association [53,54]. They characterise a shallow, low- to moderate-energy environment with elevated nutrient levels. According to Bishop [162], *Syncyclonema*-dominated assemblages may co-occur with Decapoda crustaceans (predominantly detritus feeders), where bioturbation by decapods potentially enhances nutrient recycling for suspension-feeding bivalves. This interpretation is consistent with the presence of undisturbed micaceous laminae, indicating limited sediment reworking.

(b) Shallow infralittoral facies of finely laminated greyish marls. These beds are restricted to a limited area near Condeixa-a-Nova, adjacent to the southern margin of the studied region. The new species *Syncyclonema goyi* sp. nov. is highly abundant here, with its disarticulated valves co-occurring alongside crushed shells and moulds of *Nuculana* sp., small *Pseudoptera anomala*, *Neithea hispanica*, and *Paraesa* cf. *faba*, sometimes accompanied by numerous fragments of macroalgal calcified thalli. This assemblage can be interpreted as a relict of a suspension-feeder-dominated palaeocommunity adapted to a low-energy, fully marine environment with argillaceous, fine-grained substrates. The relatively oxygenated conditions, likely maintained by periodic currents or bioturbation, combined with the proliferation of macroalgae (possibly forming hardgrounds), provided attachment substrates for small byssate bivalves.

From studies of modern aquatic environments, it is well documented that many bivalve species have biotic interactions with algae. At least 30 species, including the large Indo-Pacific *Tridacna*, are symbiotic with endozoic microalgae [163,164]. Many others, including several mussels and scallops, spend at least part of their life cycles in subtidal environments within the photic zone associated with macroalgal beds, where interactions of mutualism, commensalism, epibiosis, or parasitism can occur, e.g., [165–168]. Some of these interactions likely have existed since the early diversification and evolution of the Pectinida, and analogies can be drawn with Cretaceous species such as *Syncyclonema goyi* sp. nov. In this example, shell shape and auricle morphology clearly indicate an epibiotic lifestyle, as observed in many modern byssate scallops, which attach to a diversity of hard substrates, including the stems or thalli of macroalgae [169,170]. Such epibiosis strategy is even more frequent during post-larval juvenile stages, when algal beds can act as refugia [171–174]. In the present case, small *Syncyclonema* individuals would have locally

benefit from the calcified macroalgae available in their palaeoenvironment, which provided an advantageous substrate for byssate fixation.

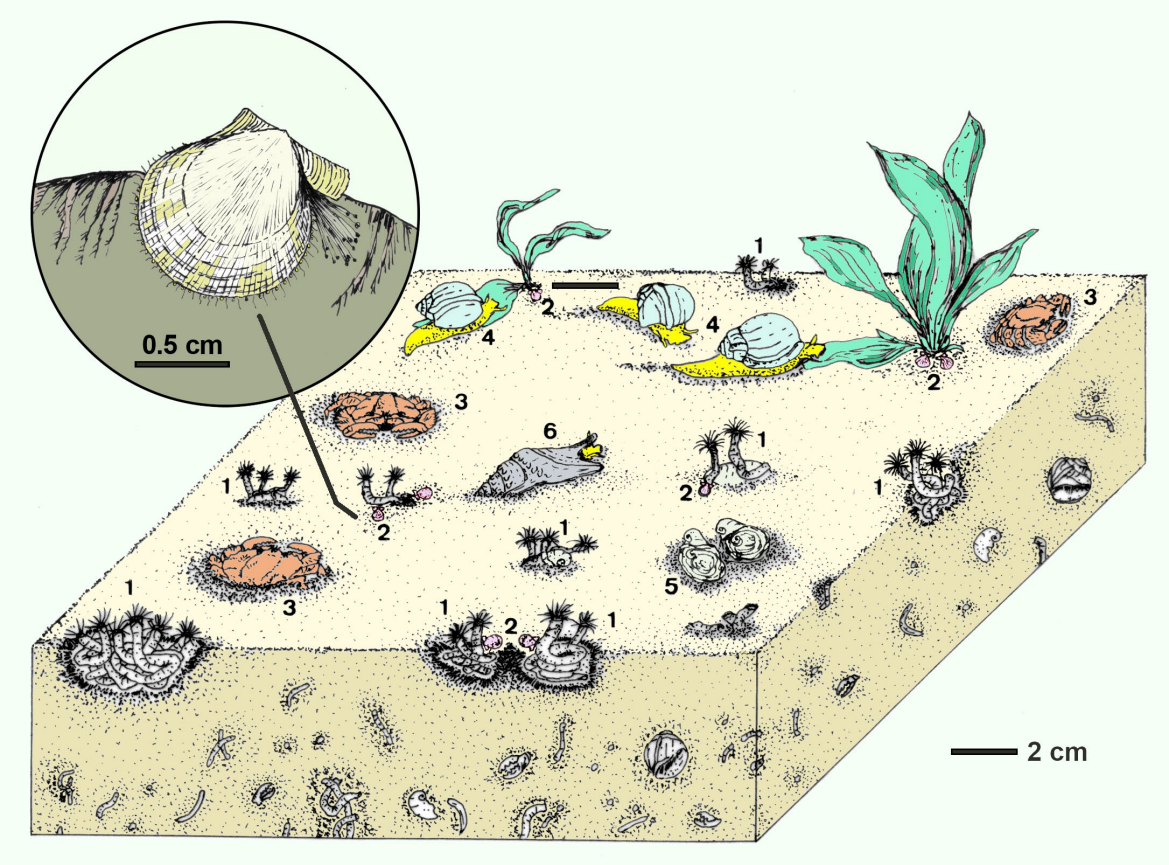

Figure 5. Block diagram depicting the palaeoenvironment and marine invertebrates associated with *Syncyclonema goyi* sp. nov. in the upper Cenomanian of the West Portuguese Carbonate Platform, in the eastern ranges of the Baixo Mondego region, near Coimbra, West Central Portugal. 1—Serpulid worms, 2—*Syncyclonema goyi* sp. nov., 3—Decapod crustaceans, 4—*Tylostoma ovatum*, 5—*Rhynchostreon suborbiculatum*, 6—*Aporrhais costae*. Algae morphology and represented colours are hypothetical.

6. Conclusions

The occurrence *Syncyclonema goyi* sp. nov. in the upper Cenomanian beds of the WPCP (Baixo Mondego region of West Portugal) highlights the relevance of pteriomorphs in shallow marine assemblages of the European Cretaceous. Notably, other species mentioned by Dhondt [4] within this group exhibit temperate–boreal biogeographic distributions throughout the Aptian–Maastrichtian interval.

The new species described here is one of the smallest Upper Cretaceous European Pectinida. Its discovery extends the range of this amphiatlantic genus from the Western Interior Seaway of North America and the Northwest and Central Europe to the non-rudist, carbonate platform facies of the Tethyan Realm. This finding provides a foundation for further research, particularly concerning the occurrence and diversification of these Entoliidae in Iberian and North African contexts.

Syncyclonema goyi sp. nov is characterised by orbicular valves, almost smooth, with unequal auricles, where the right valve is slightly more convex and bears a well-marked byssal notch. The shell sculpture consists of thin concentric growth lines and lamellae, with about 90 radial striae discernible below the outer shell layer.

Disarticulated valves and moulds of this species are quite common in open-marine, fine-grained inner shelf facies of the Tethyan West Portuguese Carbonate Platform (WPCP). In addition to the type locality of Fonte da Areia (Ançã), they have been found in several exposures near Coimbra, Trouxemil, and Condeixa-a-Nova localities, mostly in upper Cenomanian layers with *Euomphaloceras septemseriatum* and Vascoceratidae ammonites.

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Data Availability Statement: The original contributions presented in this study are included in the article; any further inquiries can be directed to the corresponding author. Taxonomical data are based in a collection of type specimens housed at the Earth Sciences Department, University of Coimbra, Coimbra, Portugal, and available for the scientific community.

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