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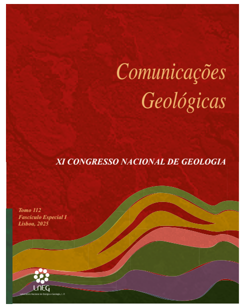
The Early and Middle Jurassic palynostratigraphy of the Lusitanian Basin (Portugal) in a proto-Atlantic context

Palinoestratigrafia do Jurássico Inferior e Médio da Bacia Lusitânica (Portugal) no contexto proto-Atlântico



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Abstract: Palynomorphs, especially dinoflagellate cysts, are important biostratigraphical and palaeoenvironmental tools and their study can be applied to the Lusitanian Basin of Portugal. A palynostratigraphical high-resolution survey was undertaken in eight Lower and Middle Jurassic (upper Sinemurian to lowermost Bathonian) sections from the Lusitanian Basin. We present the resulting biostratigraphical scheme comprising the most significant palynomorph bioevents for this interval.

Keywords: Dinoflagellate cysts, palynology, biostratigraphy, Jurassic, Lusitanian Basin.

Resumo: Os palinomorfos, em especial os quistos de dinoflagelados (dinoquistos), são uma ferramenta muito útil nos trabalhos de bioestratigrafia e interpretações paleoambientais, a qual pode ser aplicada no conhecimento da geologia da Bacia Lusitânica. Foi desenvolvido um estudo palinoestratigráfico de alta-resolução em oito perfis do Jurássico Inferior e Médio (Sinemuriano superior até à base do Bathoniano) da Bacia Lusitânica. Neste trabalho apresentamos o esquema bioestratigáfico final, com os principais bioeventos dos palinomorfos identificados neste intervalo.

Palavras-chave: Quistos de dinoflagelados, palinologia, bioestratigrafia, Jurássico, Bacia Lusitânica.

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1. Introduction

The Lusitanian Basin is located in central western Portugal and is filled mainly with Jurassic strata (Figura 1). The macro- and calcareous microfossil biostratigraphy of this basin is relatively well-studied (*e.g.* Canales and Henriques, 2008; Duarte *et al*., 2014; Figueiredo *et al*., 2014; Andrade *et al*., 2016; Henriques *et al*., 2016; Ferreira *et al*., 2019; Cabral *et al*., 2020), but comprehensive palynological data are scarce. We address this issue with a high-resolution palynostratigraphical study of a Lower and Middle Jurassic composite section from the Lusitanian Basin based mainly on dinoflagellate cysts. Due to their rapid evolution and relatively short stratigraphical ranges, dinoflagellate cysts are a powerful tool for biostratigraphy and palaeoenvironmental interpretations. We analysed 301 productive samples of marls and marly limestones for palynomorphs from eight outcrops: São Pedro de Moel, Brenha, Peniche, Fonte Coberta, Maria Pares, Vale das Fontes, São Gião and Cabo Mondego (Figura 1), together comprising an upper Sinemurian to lowermost Bathonian succession.

We aimed to produce a detailed biostratigraphical scheme with a succession of key palynomorph bioevents for this interval (Correia, 2018; Correia *et al*., 2018, 2019). Such a scheme is especially important to calibrate key global Jurassic events recorded in the Lusitanian Basin. These events are: the Toarcian Oceanic Anoxic Event (T-OAE), recently renamed "Jenkyns Event" (Reolid *et al*., 2020); the Global Boundary Stratotype Section and Point (GSSP) for the Toarcian Stage at Peniche (Rocha *et al*., 2016); the GSSP for the Bajocian Stage at Cabo Mondego (Henriques *et al*., 1994, Pavia and Enay 1997); and the Auxiliary Boundary Stratotype Section and Point (ASSP) for the Bathonian Stage at Cabo Mondego (Fernández-López *et al*., 2006, 2009). All samples, palynomorph residues, slides and figured specimens are housed in the Laboratório Nacional de Energia e Geologia (LNEG - Portuguese Geological Survey) collections, S. Mamede de Infesta, Portugal.

2. An overview of the results

This high-resolution dinoflagellate cyst record documents the earliest-known appearance of this group in the Lusitanian Basin. This inception was at the base of the late Pliensbachian, with the first occurrences (FOs) of four species: Mancod*inium semitabulatum, Luehndea spinosa, Nannoceratopsis senex* and *Nannoceratopsis gracilis* (Figs. 2, 3). These species were particularly common in the *Emaciaticeras emaciatum* and *Dactylioceras polymorphum* ammonite biozones, and the most abundant taxon was *Luehndea spinosa*. The highest stratigraphic occurrence of *Luehndea spinosa* (Figura 3a) was at the top of the *Dactylioceras polymorphum* ammonite biozone, immediately before the Jenkyns Event (Figura 2). Thus, this species is an excellent marker for the late Pliensbachian—earliest Toarcian interval.

The record also reflects dramatic changes in the marine biotas during the Jenkyns Event, a significant early Toarcian palaeoenvironmental perturbation, including last occurrences (LOs), *i.e.* extinctions of taxa. In the Lusitanian Basin, the onset of the Jenkyns Event, which occurred at the base of the *Hildaites levisoni* ammonite biozone, is marked by the extinction of *Luehndea spinosa*, the temporary disappearance of species of *Nannoceratopsis* and a general

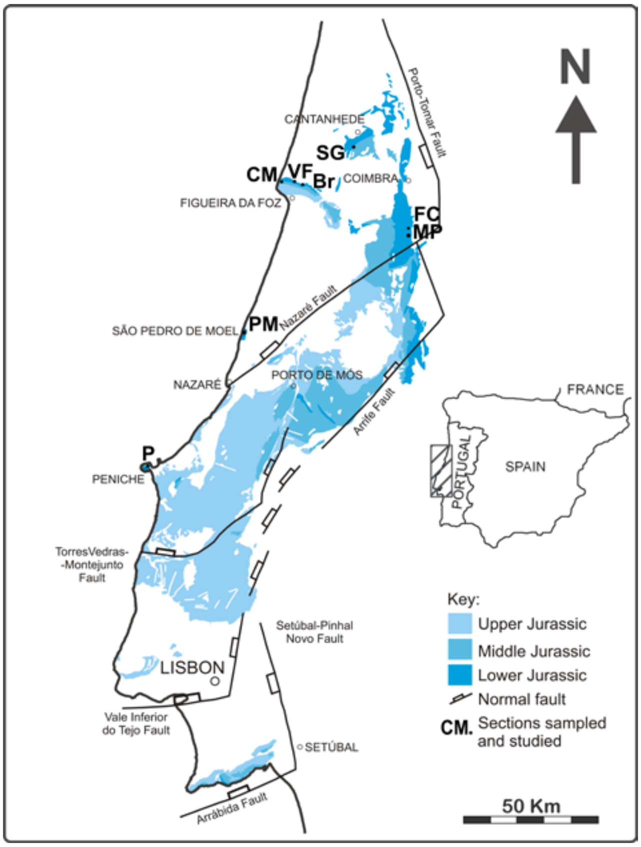

Figure 1. The geographical and geological setting of the Lusitanian Basin of western-central Portugal (adapted from Kullberg et al., 2013 and Figueiredo et al., 2014). The eight sections sampled and studied in this project are indicated by the abreviations: MP = Maria Pares (40° 3' 10"N; 8° 27' 25"W); FC = Fonte Coberta (40° 3' 44"N; 8° 27' 31"W); Br = Brenha (40° 11' 49"N; 8° 49' 55"W); VF = Vale das Fontes (40° 12' 10"N; 8° 51' 31"W); SG = São Gião (40°18' 12.63" N; 8°37'17.58"W); CM = Cabo Mondego (40°12'1.26" N; 8°54'10.4"W); PM = São Pedro de Moel (39° 43' 18"N; 9° 02' 56"W); P = Peniche (39° 22' 15"N; 9° 23' 07"W).

Figura 1. Enquadramento geográfico e geológico da Bacia Lusitânica, localizada no oeste-centro de Portugal (adaptado de Kullberg et al., 2013 e Figueiredo et al., 2014). Os oito perfis amostrados e estudados neste projeto estão indicados pelas seguintes abreviaturas: MP = Maria Pares (40° 3' 10"N; 8° 27' 25"W); FC = Fonte Coberta (40° 3' 44"N; 8° 27' 31"W); Br = Brenha (40° 11' 49"N; 8° 49' 55"W); VF = Vale das Fontes (40° 12' 10"N; 8° 51' 31"W); SG = São Gião (40°18' 12.63" N; 8°37'17.58"W); CM = Cabo Mondego (40°12'1.26" N; 8°54'10.4"W); PM = São Pedro de Moel (39° 43' 18"N; 9° 02' 56"W); P = Peniche (39° 22' 15"N; 9° 23' 07"W).

reduction in dinoflagellate cyst abundances (Figura 2; Correia *et al.*, 2017, figure 8). These bioevents correlate with the negative carbon ($\delta^{13}C_{carb}$) and oxygen ($\delta^{18}O$) isotope excursion records previously established for the Lusitanian Basin (*e.g.* Hesselbo *et al*., 2007; Suan *et al*., 2010). This dinoflagellate cyst "blackout" was caused not only by anoxia/dysoxia, but also by changes in palaeotemperatures and palaeosalinites, in particular the rapid rise of seawater palaeotemperatures, all associated with the Jenkyns Event (Correia *et al*., 2017; Ullmann *et al*., 2020).

Dinoflagellate cyst taxonomic richness and abundance remained very low throughout the entire Aalenian; only during the early Bajocian did a gradual shift in this trend occur. Greater dinoflagellate cyst recovery was observed throughout the Bajocian and earliest Bathonian, with FOs of typical European Middle Jurassic taxa such as *Dissiliodinium* spp., *Sentusidinium* spp., *Meiourogonyaulax* spp., *Ctenidodinium sellwoodii, Valensiella ovulum, Chytroeisphaeridia chytroeides, Pareodinia ceratophora, Rhynchodiniopsis pectinigera, Ellipsoidictyum* spp., *Tubotuberella dangeardii, Gonyaulacysta adecta*, *Ctenidodinium cornigerum* and complex chorate cysts (Figs. 2, 3). This increase in diversity reflects a major Middle Jurassic radiation of this planktonic group (Wiggan *et al.*, 2017).

The miospores observed in this study indicate an Early to Middle Jurassic age (*e.g.* Barrón *et al*., 2010). Despite their relatively long stratigraphical ranges, the LO of the spore *Kraeuselisporites reissingeri* at the base of Aalenian, and bioevents of the pollen *Araucariacites australis*, *Callialasporites* spp. and *Classopollis* spp. are useful additional stratigraphical indices (Figuras. 2, 3s-y). During the Early Jurassic the terrestrially derived assemblages were dominated by *Classopollis* (mostly *Classopollis classoides*), but the relative proportion of *Classopollis* decreased through the Aalenian. In contrast, the FO and diversification of the monosaccate pollen *Callialasporites,* and the increased abundance of the closely related *Araucariacites australis* are significant Middle Jurassic trends. Both taxa belong to the family Araucariaceae.

Conclusions

The Early and Middle Jurassic dinoflagellate cyst assemblages of the Lusitanian Basin are typical of this interval, but less diverse than their counterparts farther east and north in Europe. A high-resolution biostratigraphical scheme comprises 28 significant palynomorph bioevents for the late Pliensbachian to earliest Bathonian interval. The majority of these are dinoflagellate cyst acmes, FOs and LOs. These bioevents are reliable markers for this interval throughout Europe. During the Early—Middle Jurassic transition in the Lusitanian Basin, a reduction in *Classopollis* and a significant increase of araucariacean taxa were observed.

Dinoflagellate cyst extinctions and disappearances reflect the significant palaeoenvironmental changes that occurred during the Jenkyns Event (T-OAE). In contrast, two dinoflagellate radiation episodes were recorded in the Lusitanian Basin. The first episode reflects a suite of dinoflagellate cyst FOs in the basin at the base of late Pliensbachian, representing the Early Jurassic radiation event. The second episode involves the increase of dinoflagellate cyst FOs during the early Bajocian to earliest Bathonian interval, representing the Middle Jurassic radiation event (Figura 2). The dinoflagellate cyst assemblages indicate that the Lusitanian Basin is an intermediate area between the Boreal and Tethyan realms, with taxa characteristic of both. It thus represents a transition between northern and southern Europe during the early phases of the opening of the North Atlantic Ocean.

Acknowledgements

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Appendix 1. List with the cited taxa

Dinoflagellate cysts:

Chytroeisphaeridia chytroeides (Sarjeant, 1962) Downie & Sarjeant, 1965
Ctenidodinium cornigerum (Valensi, 1953) Jan du Chêne, 1985
Ctenidodinium sellwoodii (Sarjeant, 1975) Stover & Evitt, 1978
Dissiliodinium spp.
Ellipsoidictyum spp.
Gonyaulacysta adecta (Sarjeant, 1982) Riding *et al.*, 2022

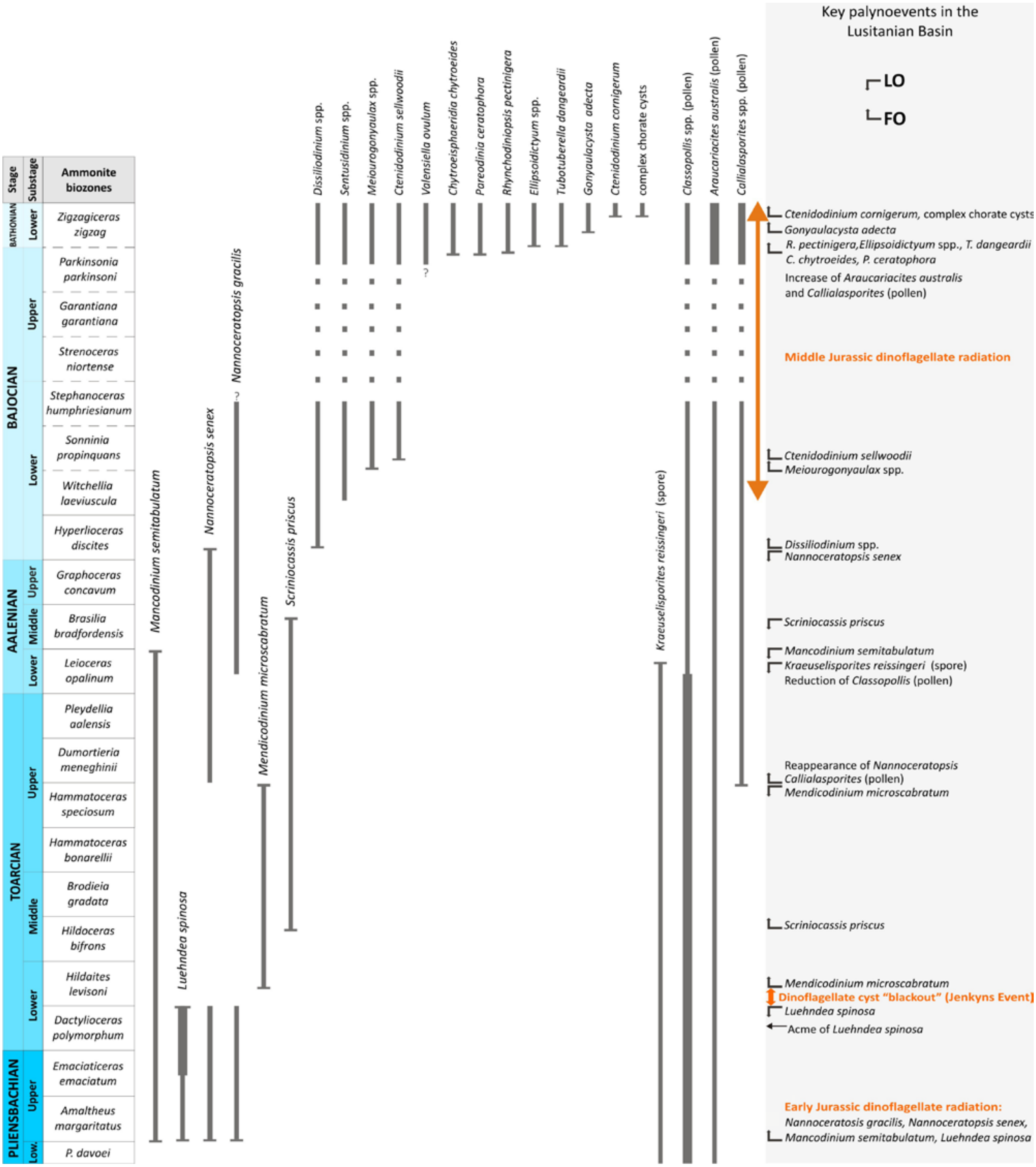

Figure 2. Palynostratigraphical scheme with the key ranges of 19 dinoflagellate cyst taxa and four miospores taxa, and selected bioevents from the upper Pliensbachian to lowermost Bathonian of the Lusitanian Basin. The miospores taxa are identified, and the rest are dinoflagellate cysts. The ends of range lines with horizontal bars represent FOs and LOs. The range lines without horizontal bars reflect discontinuous stratigraphical ranges. The dotted ranges represent inferred presences in the interval not studied (uppermost *Stephonoceras humphriesianum* to lower *Parkinsonia parkinsoni* ammonite biozones).

Figura 2. Esquema palinoestratigráfico com os intervalos de ocorrência de 19 dinoquistos e quatro miosporos, e os bioeventos mais importantes do Pliensbachiano superior até à base do Bathoniano da Bacia Lusitânica. Os taxa de miosporos estão identificados e os restantes são dinoquistos. As linhas dos intervalos estratigráficos com barras horizontais nas extremidades correspondem à primeira ocorrência e última ocorrência (i.e., aparecimento e extinção, respetivamente). A ausência da barra horizontal significa uma interrupção no intervalo estratigráfico conhecido para esse taxon. Os intervalos a tracejado representam ocorrências inferidas de uma sucessão não estudada (topo da biozona de amonites *Stephonoceras humphriesianum*–base da biozona de amonites *Parkinsonia parkinsoni*).

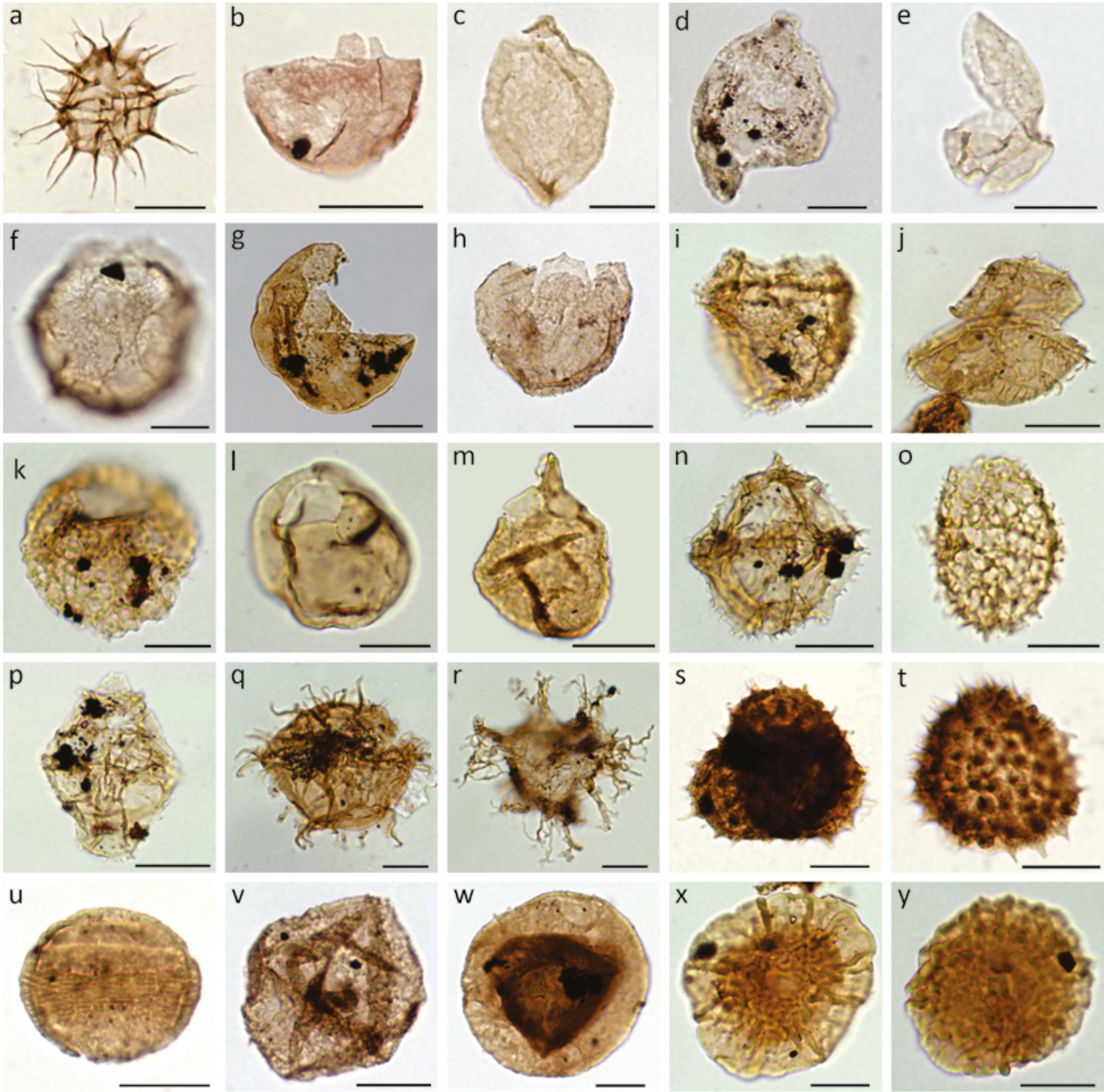

Figure 3. Dinoflagellate cysts (a-r) and miospores (s-y) from the Lower and Middle Jurassic of the Lusitanian Basin. The section (VF = Vale das Fontes; MP = Maria Pares; P = Peniche; CM = Cabo Mondego; PM = São Pedro de Moel), substage, sample number and England Finder coordinates are provided below. All scale bars represent 20 µm. (a) *Luehndea spinosa*, VF, lower Toarcian, PVF8, O24. (b) *Mancodinium semitabulatum*, VF, lower Toarcian, PVF1, H56/2. (c) *Nannoceratopsis senex*, P, upper Pliensbachian, P-25, O48/4. (d) Nannoceratopsis gracilis, P, lower Toarcian, P6, G28/3. (e) *Mendicodinium microscabratum*, MP, lower Toarcian, PZ16, T36/1. (f) *Scriniocassis priscus*, MP, upper Toarcian, PZ77, C32. (g) *Dissiliodinium* sp., CM, lower Bajocian, AB192, R42. (h) *Sentusidinium* sp., CM, lower Bajocian, AB116, W51/2. (i) *Meiourogonyaulax* sp., CM, upper Bajocian, Bt110, N24/1. (j) *Ctenidodinium sellwoodii*, CM, upper Bajocian, Bt106, R25/1. (k) *Valensiella ovulum*, CM, lower Bathonian, Bt134, H33. (l) *Chytroeisphaeridia chytroeides*, CM, lower Bathonian, Bt164, N35. (m) Pareodinia ceratophora, CM, upper Bajocian, Bt106, R31. (n) *Rhynchodiniopsis pectinigera*, CM, lower Bathonian, Bt200, J25/3. (o) *Ellipsoidictyum* sp., CM, lower Bathonian, Bt200, P44. (p) *Tubotuberella dangeardii,* CM, lower Bathonian, Bt126, O25/1. (q) *Ctenidodinium cornigerum*, CM, lower Bathonian, Bt220, H24. (r) Indeterminate chorate dinoflagellate cyst, CM, lower Bathonian, Bt210, P27. (s) Tetrad of *Kraeuselisporites reissingeri*, VF, lower Toarcian, PVF5, E34/3. (t) *Kraeuselisporites reissingeri*, VF, lower Toarcian, PVF10, H26/4. (u) *Classopollis classoides*, PM, upper Sinemurian, PM2, Q36. (v) *Araucariacites australis*, CM, lower Bajocian, AB178a, Q23/2. (w) *Callialasporites turbatus*, CM, lower Bajocian, M341, N23/2. (x) *Callialasporites dampieri*, CM, lower Bathonian, Bt184, U55/2. (y) *Callialasporites segmentatus*, CM, lower Bathonian, Bt184, H29/2.

Figura 3. Dinoquistos (a-r) e miosporos e (s-y) do Jurássico Inferior e Médio da Bacia Lusitânica. O perfil (VF = Vale das Fontes; MP = Maria Pares; P = Peniche; CM = Cabo Mondego; PM = São Pedro de Moel), subandar, número da amostra e as coordenadas England Finder são identificados. Todas as escalas representam 20 µm. (a) *L. spinosa*, VF, Toarciano inf., PVF8, O24. (b) *M. semitabulatum*, VF, Toarciano inf., PVF1, H56/2. (c) *N. senex,* P, Pliensbachiano sup., P-25, O48/4. (d) *N. gracilis*, P, Toarciano inf., P6, G28/3. (e) *M. microscabratum*, MP, Toarciano inf., PZ16, T36/1. (f) *S. priscus*, MP, Toarciano sup., PZ77, C32. (g) *Dissiliodinium* sp., CM, Bajociano inf., AB192, R42. (h) *Sentusidinium* sp., CM, Bajociano inf., AB116, W51/2. (i) *Meiourogonyaulax* sp., CM, Bajociano sup., Bt110, N24/1. (j) *C. sellwoodii*, CM, Bajociano sup., Bt106, R25/1. (k) *V. ovulum*, CM, Bathoniano inf., Bt134, H33. (l) *C. chytroeides*, CM, Bathoniano inf., Bt164, N35. (m) *P. ceratophora*, CM, Bajociano sup., Bt106, R31. (n) *R. pectinigera*, CM, Bathoniano inf., Bt200, J25/3. (o) *Ellipsoidictyum* sp., CM, Bathoniano inf., Bt200, P44. (p) T. *dangeardii,* CM, Bathoniano inf., Bt126, O25/1. (q) C. cornigerum, CM, Bathoniano inf., Bt220, H24. (r) Dinoquisto corado indeterminado, CM, Bathoniano inf., Bt210, P27. (s) Tetrada de *K. reissingeri*, VF, Toarciano inf., PVF5, E34/3. (t) *K. reissingeri*, VF, Toarciano inf., PVF10, H26/4. (u) *C. classoides*, PM, Sinemuriano sup., PM2, Q36. (v) CM, Bajociano inf., AB178a, Q23/2. (w) *C. turbatus,* CM, Bajociano inf., M341, N23/2. (x) *C. dampieri*, CM, Bathoniano inf., Bt184, U55/2. (y) *C. segmentatus*, CM, Bathoniano inf., Bt184, H29/2.

Luehndea spinosa Morgenroth, 1970
Mancodinium semitabulatum Morgenroth, 1970
Meiourogonyaulax spp.
Mendicodinium microscabratum Bucefalo Palliani *et al.*, 1997
Nannoceratopsis gracilis Alberti, 1961
Nannoceratopsis senex van Helden, 1977
Pareodinia ceratophora Deflandre, 1947
Rhynchodiniopsis pectinigera (Gocht, 1970) Riding *et al.*, 2022

Scriniocassis priscus (Gocht, 1979) Below, 1990
Sentusidinium spp.
Tubotuberella dangeardii (Sarjeant, 1968) Stover & Evitt, 1978
Valensiella ovulum (Deflandre, 1947) Eisenack, 1963

Miospores:

Callialasporites dampieri (Balme, 1957) Dev, 1961 (pollen)
Callialasporites segmentatus (Balme, 1957) Srivastava, 1963 (pollen)
Callialasporites turbatus (Balme, 1957) Schulz, 1967 (pollen)
Classopollis classoides (Pflug, 1953) Pocock & Jansonius, 1961 (pollen)
Kraeuselisporites reissingeri (Harris, 1957) Morbey, 1975 (spore)

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