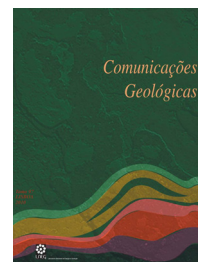


Palynomorph succession of the Upper Pliensbachian–Lower Toarcian of the Peniche section (Portugal)

Sucessão de palinórfos ao longo do Pliensbaquiano superior – Toarcião inferior no perfil de Peniche (Portugal)

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Abstract: The Peniche section in the Lusitanian Basin (western Portugal) provides an exceptional, continuous record of the Portuguese Lower Jurassic, and is the candidate for the Global Boundary Stratotype Section and Point for the base of the Toarcian. This paper reports a palynological study of the Margaritatus, Spinatum, Polymorphum and Levisoni zones. Forty eight levels yielded representative and well preserved palynomorph assemblages. Fifty seven palynomorph taxa were recorded: 19 spore taxa, 20 pollen taxa, 11 acanthomorph acritarchs, 4 prasinophytes and 3 dinocyst taxa. The Pliensbachian levels show a characteristic predominance of *Classopollis* and a wide diversity of aquatic palynomorphs. The Toarcian levels are characterised by the pollen grains of *Spheripollenites* and a progressive reduction in the diversity of aquatic palynomorphs.

Keywords: Palynology, Biostratigraphy, Pliensbachian, Toarcian Stratotype, Lower Jurassic, Lusitanian Basin.

Resumo: O perfil de Peniche, localizado na Bacia Lusitânica (Oeste de Portugal), mostra um registo contínuo e excepcional no contexto do Jurássico Inferior português, que inclui o candidato a estratotipo do limite Pliensbaquiano–Toarcião. Neste âmbito foi desenvolvido um estudo palinológico envolvendo as zonas Margaritatus, Spinatum, Polymorphum e Levisoni, tendo sido analisados 48 níveis com associações representativas e bem preservadas de palinórfos. Foram identificados 57 taxa de palinórfos: 19 de esporos, 20 de pólenes, 11 de acritarcas Acanthomorpha, 4 de prasinófitas e 3 de dinocistos. Os níveis do Pliensbaquiano são caracterizados pela larga predominância de *Classopollis* e pela diversidade de palinórfos aquáticos. Os grãos de pólen *Spheripollenites* e a diminuição progressiva da diversidade de palinórfos aquáticos caracterizam os níveis do Toarcião.

Palavras-chave: Palinologia, Biostratigrafia, Pliensbaquiano, Estratotipo do Toarcião, Jurássico Inferior, Bacia Lusitânica.

1. Introduction

The Pliensbachian and Toarcian series in the Lusitanian Basin (Portugal) are dominated by hemipelagic deposits composed of marl/limestone alternations very rich in nektonic (ammonites and belemnites) and benthic (bivalves, brachiopods, crinoids and siliceous sponges) macrofauna (Duarte & Soares, 2002; Duarte, 2007). These units are biostratigraphically well constrained by ammonites and calcareous nannofossils (see Rocha, 2007 and references therein).

Pliensbachian and Toarcian deposits are clearly exposed in several places in this basin. The best Portuguese section is found in the Peniche Peninsula on the Atlantic coast, 80 km north of Lisbon (Fig. 1). Its exceptional Upper Pliensbachian–Lower Toarcian transition outcrop led the IUGS to propose its recognition as the Global Boundary Stratotype Section and Point (GSSP) for the base of the Toarcian (Elmi, 2006; Rocha, 2007).

The present work reports a complete study of the palynological content of the Upper Pliensbachian–Lower Toarcian rocks cropping out in the Peniche section. Qualitative and semiquantitative analyses were performed to identify the palynological assemblages, which were calibrated using the ammonoid-based biostratigraphic scale. However, the relationships between the palynomorph record and the important sedimentary and palaeoenvironmental changes observed across the studied interval at Peniche (*e.g.* Wright & Wilson, 1984; Duarte *et al.*, 2004, 2010; Hesselbo *et al.*, 2007; Suan *et al.*, 2008, 2010; Mattioli *et al.*, 2009; Reggiani *et al.*, 2010; Silva *et al.*, 2011) will be discussed in a future work.

2. Materials and methods

The whole of the continuous section between the Margaritatus and Levisoni zones (*e.g.* Mouterde, 1955) was analysed. Earlier stratigraphic studies show this interval to include the upper part of the Vale das Fontes Formation (marly limestones with organic facies), the Lemedo

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Formation, and the base of the Cabo Carvoeiro Formation (Cabo Carvoeiro 1 and 2) (Duarte, 1997, 2007; Duarte & Soares, 2002; Duarte *et al.*, 2004; Oliveira *et al.*, 2006; Silva *et al.*, 2011). Fifty one rock samples were collected and examined following the standard palynological technique (Batten, 1999), i.e., acid treatment with HCl, HF and HNO₃ at high temperature. The residues were concentrated using 500, 250, 75, 50 and 12 µm sieves. Samples were mounted in glycerine jelly and examined by light microscopy using an Olympus BX51 optical microscope. All samples were prepared at the ALICONTROL laboratory (Madrid, Spain). At least 500 palynomorphs were examined for each sample to determine species ratios.

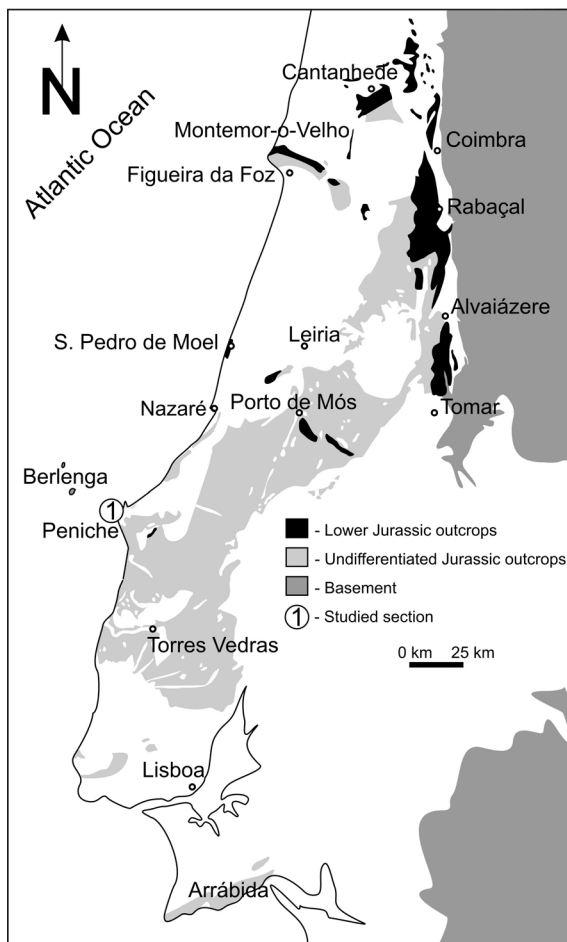


Fig.1. Location of the Peniche section in the Lusitanian Basin (based on Duarte *et al.*, 2010).

Fig.1. Localização da secção de Peniche na Bacia Lusitânica (baseado em Duarte *et al.*, 2010).

3. Results

Forty eight samples – 12 from the Vale das Fontes Formation (lower part of the Margaritatus Zone), 12 from the Lemedé Formation (upper part of the Margaritatus Zone and the whole of the Spinatum Zone), 9 from the first member of the Cabo Carvoeiro Formation (Polymorphum Zone) and 15 from the second (Levisoni Zone) (Fig. 2) – yielded representative and well-preserved assemblages.

About 57 palynomorph taxa were recorded. The assemblages of the Pliensbachian–Toarcian levels were characterized by a low diversity of palynomorphs. Eleven species of acanthomorph acritarchs were recorded over the succession, with the genus *Micrhystridium* present in almost all the studied levels (Fig. 2). Indeed, *M. lymensis* (Plate 1.6), its variety *rigidum* (Pl 1.13) and *Micrhystridium* sp. were conspicuous especially in the uppermost Pliensbachian levels. The appearance over the succession of many other species of *Micrhystridium*, such as *M. deflandrei*, *M. fragile*, *M. cf. minutispinum*, *M. stellatum* (Pl. 1.12), *M. rarispinum* and *M. wattonensis*, is also remarkable. Dinocysts were generally poorly preserved, and only three taxa could be identified: *Nannoceratopsis* sp., *Hystrichosphaeridium* sp. (Pl. 1.4) and *Peridinales* gen. et sp. indet. They always appeared in low numbers, except in one level of the Margaritatus Zone and one other in the Levisoni Zone. In the former, more than 50 specimens were recorded. Prasinophytes were also found in small numbers. *Cymathiosphaera pachythea* (Pl. 1.5) was seen at the base of the Levisoni Zone, and *Tasmanites* sp. (Pl. 1.1) in the Margaritatus and Polymorphum zones.

Miospores are predominant in all the samples analysed; 19 spore taxa and 20 pollen types were found. Spores of vascular cryptogams are scarce. However, they were present in small numbers at the extreme base of the Polymorphum and Levisoni zones. The base of the Polymorphum Zone shows the conspicuous presence of *Deltoidospora mesozoica* and *Uvaesporites argenteaeformis*. *Classopollis* (Pl. 1.3 and 15) and *Spheripollenites* (Pl. 1.8) are the most abundant palynomorphs throughout the succession. The former genus is most common in the Pliensbachian levels whereas the latter appeared in the Toarcian in very great numbers. An inaperturate pollen type (*Inaperturopollenites* sp.) appeared constantly throughout the section. The genus *Alisporites* (Pl. 1.16) is the best represented bisaccate pollen grain; this is only present in small numbers at certain levels in the Margaritatus and Polymorphum zones.

The Margaritatus Zone is characterized by the great abundance of *Classopollis*. According to descriptions made by Peyrot *et al.* (2007), this genus was mainly represented by *C. classoides* (Pl. 1.3), *C. torosus* (Pl. 1.15) and *Classopollis* spp. This zone shows the greatest diversity of pollen grains (18 taxa) and of vascular cryptogam spores (13 taxa). Aquatic palynomorphs such as *M. lymensis* and the dinoflagellate cyst *Hystrichosphaeridium* sp., as well as *Baltisphaeridium micropunctatum*, *M. intromittum* and *Veryhachium* sp. (Pl. 1.14), appear in low numbers in some levels. *Baltisphaeridium* sp., *Echinatisporites* cf. *varispinosus*, *Lycopodiumsporites reticulumsporites*, *Eucommiidites troedsonii* and *Callialasporites turbatus* (Pl. 1.7) are recorded only in this zone.

The Spinatum Zone also shows the strong presence of *Classopollis*. However, *C. classoides* and *C. torosus* became less abundant through the zone. The pollen grains of *Spheripollenites* begin to appear in abundance. Spores are very scarce; *Cyathidites minor*, *Baculatisporites comaumensis* (Pl. 1.10) and *Kraeuselisporites reissingeri* are rare. However, this zone shows an increase in aquatic

palynomorphs; indeed, their most diverse assemblages are recorded here. The best represented aquatic palynomorph is the acritarch *M. lymensis* (Pl. 1.5). In the upper part of the zone it is abundant, together with *B. micropunctatum* (Pl. 1.2) and dinoflagellate cysts. Indeed, the Spinatum Zone, with 15 taxa, shows the greatest aquatic palynomorph diversity of the entire Peniche section.

The levels of the Polymorphum Zone show a drastic reduction in the number of *Classopollis* pollen grains and a notable increase in those of *Spheripollenites* spp. The lowest levels of this zone show conspicuous amounts of spores, mainly those of *Deltoidospora mesozoica* and *Uvaesporites argenteaeformis*. This diversity rapidly decreases through the zone and, with the exception of *Classopollis* and *Spheripollenites*, both spores and pollen grains eventually became very scarce. Few aquatic palynomorphs are recorded for this zone. *Micrhystridium* occurs in the upper part of the zone. The spores *Cingutritetes* sp. and *Lycopodiacidites rugulatus* are only recorded in this zone. In addition, 11 species of palynomorph [e.g. *Kraeuselisporites reissingeri* (Pl. 1.11), *Leptolepidites macroverrucosus* (Pl. 1.9) and *Alisporites* sp. (Pl. 1.16)] make their last appearances.

The diversity falls drastically in the Levisoni Zone. Here, *Spheripollenites* (Pl. 1.8) is the best represented palynomorph, making up more than 90% of the total. The uppermost level studied mainly shows *Spheripollenites*, acritarchs and dinoflagellate cysts. The latter group is mainly represented by poorly preserved *Nannoceratopsis* sp. and *Hystriospheraidium* spp.

4. Discussion

The assemblages observed in the Peniche section include temporally long-ranging palynomorphs, at least according to the stratigraphic ranges deduced from the results of previous studies (e.g. Wall, 1965; Filatoff, 1975; Guy-Ohlson, 1986, 1990; Batten & Koppelhus, 1996). The species *Alisporites bilateralis*, *Araucaricites australis*, *Baculatisporites comaumensis*, *Classopollis classoides*, *C. torosus*, *Cyathidites australis*, *Eucommiidites troedsonii*, *Kraeuselisporites reissingeri*, *Lycopodiacidites rugulatus*, *Micrhystridium lymensis*, *Perinopollenites elatoides*, *Spheripollenites psilatus*, *Trachysporites fuscus*, *Uvaesporites argenteaeformis* and *Vitreisporites pallidus* appear to have been present from the Triassic, through the Lower Jurassic, and (for the majority) into the Cretaceous. Species such as *Cerebropollenites macroverrucosus*, *Cycadopites follicularis*, *Deltoidospora mesozoica*, *Dictyophyllidites harrisii*, *Cyathidites minor*, *Ischyosporites variegatus* and *Leptolepidites macroverrucosus* also show long ranges beginning in the Lower Jurassic and finishing in the Cretaceous. *Callialasporites turbatus* first occurs in the Margaritatus Zone (level PE585; Fig. 2); this is the first record of this species for the Toarcian of northwestern Europe (Batten & Koppelhus, *op. cit.*).

According to Davies (1985) and Veiga de Oliveira *et al.* (2007), the studied interval is characterized by 12 species of dinocyst. In this work only three such taxa could be recorded, with *Hystriospheraidium* sp. and

Nannoceratopsis sp. restricted to the Jurassic. The biostratigraphic ranges of the identified acritarchs and prasinophycean algae are scarcely known outside of the Lower Jurassic.

Near the Pliensbachian–Toarcian boundary, *Classopollis* (an over-represented palynomorph in Pliensbachian levels) undergoes a conspicuous decline. *C. torosus* disappears at the base – level 337P3 – of the Toarcian (Fig. 2) and *C. classoides* decreases in abundance from the mentioned level. However, *Spheripollenites* increases, becoming the most characteristic pollen grain of the Polymorphum and Levisoni zones. An increase in miospore diversity can also be observed in level 337P3. *Classopollis* is also well represented in other Upper Pliensbachian locations in France (Boutet, 1981) and Sweden (Guy-Ohlson, 1990). The change in dominance from *Classopollis* to *Spheripollenites* around the Pliensbachian–Toarcian boundary has been reported for the Iberian Range in the Rambla del Salto Section (Barrón *et al.*, 1999). The predominance of *Spheripollenites* in the Lower Toarcian seems to be related to a gradual increase in inaperturate palynological taxa (Filatoff, 1975).

The Spinatum Zone is distinguished by an increase in the abundance and diversity of aquatic palynomorphs. In the Polymorphum Zone their numbers begin to reduce, and become very low in the Levisoni Zone. The occurrence of *Micrhystridium* through most of the Levisoni Zone may indicate it to have been ubiquitous and well able to survive in stressed environments with high seawater temperatures and low nutrient availability. This acritarch is also predominant among the aquatic palynomorphs in Iberian, warm marine, epeiric carbonate platforms of the Upper Toarcian and Lower Aalenian (Barrón *et al.*, 2010).

5. Conclusions

The palynological study of the Peniche section, the proposed GSSP for the base of the Toarcian, led to the identification of 57 palynomorph taxa, most with long stratigraphic ranges. *Callialasporites turbatus*, which is recorded from the Late Toarcian in northwestern Europe, is recorded for the first time in the Pliensbachian (Margaritatus Zone) of the Iberian Peninsula.

Like the Pliensbachian assemblages of northern and western Europe, the palynological assemblages corresponding to the Margaritatus and Spinatum zones are characterized in the Peniche section by the predominance of *Classopollis*. In addition, the Spinatum Zone shows conspicuous amounts of aquatic palynomorphs; the presence of many different species of the acritarch genera *Micrhystridium*, *Baltisphaeridium* and *Veryhachium* is remarkable. Over the Toarcian Polymorphum and Levisoni zones, *Classopollis* pollen was replaced by that of *Spheripollenites*, and the abundance and diversity of aquatic palynomorphs gradually fell. Among the acritarchs, only the genus *Micrhystridium* was important in the Levisoni Zone. Possibly the properties of the seawater present at the time were different than during the Upper Pliensbachian and lowermost Toarcian.

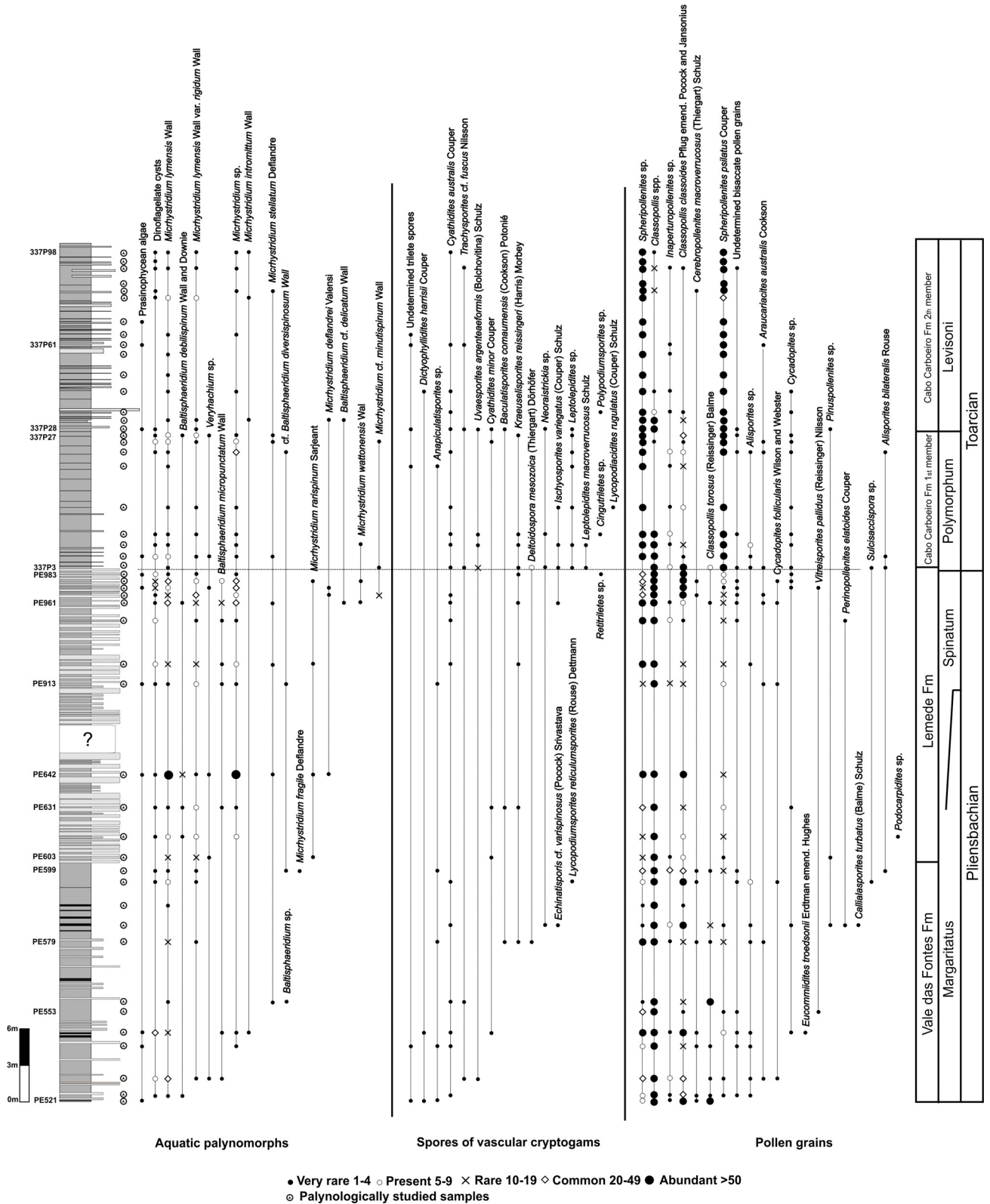


Fig.2. Stratigraphic distribution of palynomorphs of the Upper Pliensbachian-Lower Toarcian succession in the Peniche section. Lithostratigraphic units based on Duarte & Soares (2002); ammonite biostratigraphy based and modified from Mouterde (1955), Elmi (2006) and Silva *et al.* (2011).

Fig.2. Distribuição estratigráfica dos palinomorfnos ao longo do Pliensbaquiano superior – Toarciano inferior no perfil de Peniche. Unidades litostratigráficas baseadas em Duarte & Soares (2002); biostratigrafia de amonites baseada e modificada de Mouterde (1955), Elmi (2006) e Silva *et al.* (2011).

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Plate 1

1.- *Tasmanites* sp. (phycoma of prasinophycean algae), level PE544, Pliensbachian (Margaritatus Zone); **2.-** *Baltisphaeridium micropunctatum* Wall, 1965 (acanthomorph acritarch), level PE961, Pliensbachian (Spinatum Zone); **3.-** *Classopollis torosus* (Reissinger, 1950) Balme, 1957 (group of cheirolepidiaceous pollen grains), level PE579, Pliensbachian (Margaritatus Zone); **4.-** *Hystriosphraeridium* sp. (chorate dinocyst), level 337P27, Toarcian (Polymorphum Zone); **5.-** *Cymathiosphaera pachyteca* Eisenack, 1957 (prasinophycean algae), level 337P28, Toarcian (Levisoni Zone); **6.-** *Micrhystridium lymensis* Wall, 1965 (acanthomorph acritarch), level PE961, Pliensbachian (Spinatum Zone); **7.-** *Callialasporites turbatus* (Balme, 1957) Schulz, 1967 (pollen grain of an araucariaceous conifer), level PE585, Pliensbachian (Margaritatus Zone); **8.-** *Spheripollenites psilatus* Couper, 1958 (tetrad of uncertain gymnospermous origin), level 337P38, Toarcian (Levisoni Zone); **9.-** *Leptolepidites macroverrucosus* Schulz, 1967 (spore of a lycopodiaceous cryptogam), level 337P3, Toarcian (Polymorphum Zone); **10.-** *Baculatisporites comaumensis* (Cookson, 1953) Potonié, 1956 (spore of an Osmundaceous fern), level PE631, Pliensbachian (Margaritatus Zone); **11.-** *Kraeuselisporites reissingeri* (Harris, 1957) Morbey, 1975 (tetrad of sellaginellaceous spores), level 337P3, Toarcian (Polymorphum Zone); **12.-** *Micrhystridium stellatum* Deflandre, 1937 (acanthomorph acritarch), level PE553, Pliensbachian (Margaritatus Zone); **13.-** *Micrhystridium lymensis* Wall, 1965 var. *rigidum* Wall, 1965 (acanthomorph acritarch), level PE603, Pliensbachian (Spinatum Zone); **14.-** *Veryhachium* sp. (Polygonomorpha acritarch), level PE529, Pliensbachian (Margaritatus Zone); **15.-** *Classopollis classoides* (Plfug, 1953) Pocock & Jansonius, 1961 (monad of a cheirolepidiaceous pollen grain), PE544, Pliensbachian (Margaritatus Zone); **16.-** *Alisporites* sp. (poorly preserved bisaccate pollen grain), level 337P3, Toarcian (Polymorphum Zone).

Scale bars: figs. 1, 3, 5–8, 10–11, 15–16 = 20 µm; figs. 2, 4, 9, 12–14 = 10 µm.

Estampa 1

1.- *Tasmanites* sp. (ficoma de alga prasinófitas), nível PE544, Pliensbaquiano (Zona Margaritatus); **2.-** *Baltisphaeridium micropunctatum* Wall, 1965 (acritarca Acanthomorpha), nível PE961, Pliensbaquiano (Zona Spinatum); **3.-** *Classopollis torosus* (Reissinger, 1950) Balme, 1957 (grãos de pólen de coníferas da família Cheirolepidiaceae), nível PE579, Pliensbaquiano (Zona Margaritatus); **4.-** *Hystriosphraeridium* sp. (dinocisto corado), nível 337P27, Toarciano (Zona Polymorphum); **5.-** *Cymathiosphaera pachyteca* Eisenack, 1957 (alga prasinófitas), nível 337P28, Toarciano (Zona Levisoni); **6.-** *Micrhystridium lymensis* Wall, 1965 (acritarca Acanthomorpha), nível PE961, Pliensbaquiano (Zona Spinatum); **7.-** *Callialasporites turbatus* (Balme, 1957) Schulz, 1967 (grão de pólen de coníferas araucariáceas), nível PE585, Pliensbaquiano (Zona Margaritatus); **8.-** *Spheripollenites psilatus* Couper, 1958 (tétrade de grãos de pólen de gimnospermas mesozóicas desconhecidas), nível 337P38, Toarciano (Zona Levisoni); **9.-** *Leptolepidites macroverrucosus* Schulz, 1967 (esporo de criptógama de Lycopodiaceae), nível 337P3, Toarciano (Zona Polymorphum); **10.-** *Baculatisporites comaumensis* (Cookson, 1953) Potonié, 1956 (esporo de fetos da família Osmundaceae), nível PE631, Pliensbaquiano (Zona Margaritatus); **11.-** *Kraeuselisporites reissingeri* (Harris, 1957) Morbey, 1975 (tétrade de esporos de Sellaginellaceae), nível 337P3, Toarciano (Zona Polymorphum); **12.-** *Micrhystridium stellatum* Deflandre, 1937 (acritarca Acanthomorpha), nível PE553, Pliensbaquiano (Zona Margaritatus); **13.-** *Micrhystridium lymensis* Wall, 1965 var. *rigidum* Wall, 1965 (acritarca Acanthomorpha), nível PE603, Pliensbaquiano (Zona Spinatum); **14.-** *Veryhachium* sp. (acritarca do grupo Polygonomorpha), nível PE529, Pliensbaquiano (Zona Margaritatus); **15.-** *Classopollis classoides* (Plfug, 1953) Pocock & Jansonius, 1961 (mônade de grão de pólen de Cheirolepidiaceae), nível PE544, Pliensbaquiano (Zona Margaritatus); **16.-** *Alisporites* sp. (grão de pólen bissacado mal preservado), nível 337P3, Toarciano (Zona Polymorphum).

Escala das barras: figs. 1, 3, 5–8, 10–11, 15–16 = 20 µm; figs. 2, 4, 9, 12–14 = 10 µm.

