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**LOWER JURASSIC BENTHIC FORAMINIFERAL ASSEMBLAGES FROM
SHALLOW MARINE PLATFORM CARBONATES OF MALLORCA (SPAIN):
STRATIGRAPHIC IMPLICATIONS**

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Abstract

The stratigraphic distribution of larger benthic foraminifera and other microfossils recognizable in thin sections has been investigated in three stratigraphic profiles (Son Maina, S'Heretat and Cuevas de Artà) along the Lower Jurassic shallow-water carbonate platform succession (Es Barraca Member) of the Llevant Mountains in the Mallorca Island. Here, the microfossil assemblage contains abundant benthic foraminifera and calcareous algae, including the microproblematic *Thaumatoporella parvovesiculifera* (Raineri) and the typical Liassic species *Palaeodasycladus mediterraneus* (Pia), which has allowed a better age constraint of the succession. Four consecutive biozones (scheme of [Septfontaine 1984](#)) have been recognized based on the stratigraphic distribution of imperforate foraminifera, which are documented by the first time in the Balearic Basin: Biozone A (interval Zone) is characterized by the occurrence of small *Siphovalvulina* sp. and *Mesoendothyra* sp. and some *Lituosepta* ancestors. Biozone B (lineage Zone), whose base is marked by the first occurrence of *L. recoarensis* Cati and the top by the first appearance of primitive forms of *Orbitopsella*. Biozone B/C1 transition, characterized by the presence of very primitive forms of *Orbitopsella*. Finally, Biozone C1 (lineage Zone) marked by the first occurrence of *Orbitopsella* aff. *primaeva* (Henson) but still with *L. recoarensis*. This distribution of foraminiferal zones is consistent with a Sinemurian age for the Es Barraca Member, with its top very unlikely penetrating into the Pliensbachian. The proposed

biostratigraphic scheme is comparable with those established for other western Tethyan margins such the High Atlas of Morocco and the Betic Cordillera in southern Spain. The reconstruction of the depositional transect across these profiles shows the progressive loss of the upper biozones towards the northeast, evidencing the existence of significant hiatuses in some sections of the Llevant Mountains domain, and allowing to infer an intra-Pliensbachian early stage of platform fragmentation and erosion, or alternatively non-deposition, probably coeval with progradation of deltaic siliciclastics to the northwest part of the Mallorca island. The new biostratigraphic data presented here highlights the need to review and clarify the current stratigraphic scheme established for the Lower Jurassic of Mallorca.

Key words: Sinemurian–earliest Pliensbachian, benthic foraminifera, biozones, carbonate platform, Es Barraca Member, Balearic Basin

1 Introduction

Shallow-marine carbonates of Early Jurassic age developed widely in the western Tethyan margins (Fig. 1). These shallow water carbonate environments experienced important architectural and compositional changes in a context of rifting related with the break-up of Pangea and associated with important circulation, environmental changes and an eustatic sea-level rise (e.g. [Zempolich 1993](#); [Ruiz-Ortiz et al. 2004](#); [Massetti et al. 2016](#); [Preto et al. 2017](#); [Rychlinski et al. 2018](#); [Franceschi et al. 2019](#)). These changes are recorded in the lithostratigraphic and biostratigraphic record of the Tethyan platforms. These events coincided also with the faunistic turnover that occurred in the Early Jurassic after the catastrophic Triassic-Jurassic (T/J) boundary mass extinction, which resulted in a gradual recovering and diversification of the shallow-water benthic communities, in which larger benthic foraminifera played a primordial role. So that, the poorly diversified benthic associations of the Hettangian evolved during the early Sinemurian into a more diversified *Siphovavulina*- and *Textularia*-dominated assemblages, and finally into more complicated lito-lids during the late Sinemurian–Pliensbachian, providing an important biostratigraphic tool (Fig. 2) ([Septfontaine 1984, 1988](#); [Bassoullet 1997](#); [Fugagnolli and Loriga 1998](#); [Kabal and Tasli 2003](#); [Mancinelli et al. 2005](#); [Boudagher-Fadel and Bosence 2007](#); [Velic 2007](#); [Gale 2014](#)).

The Lower Jurassic succession of the Balearic Islands (Fig. 3) is a good representative of the evolution of one of these carbonate platforms associated to all the above-mentioned events ([Álvaro et al. 1989](#); [Rosales et al. 2018](#); [Sevillano et al. 2019](#)). A comprehensible study of facies analysis and platform evolution of the shallow-water carbonates (Es Barraca Member) has been provided recently in [Sevillano et al. \(2019\)](#). The microfossil content of the Es Barraca Mb was studied in the past by [Fallot \(1922\)](#), [Colom \(1966, 1970, 1980\)](#), and [Colom and Dufaure \(1962\)](#), but not detailed stratigraphic distribution of the recognized foraminifera taxa and biozones was given before. This new micropaleontological study has three aims: First, to establish a foraminiferal biostratigraphy of this shallow-water carbonate succession and to use the distribution of biozones for improving the age resolution of the Es Barraca Member (particularly its top) and, therefore, its relationship with other Lower Jurassic stratigraphic units, for a better definition of the current Lower Jurassic stratigraphic scheme of the Mallorca island. Second, to follow changes, in the studied samples, of the gradual evolution of the Orbitopsellids s.l. during the Lower Jurassic. Third, to use the new biostratigraphic information for getting a better understanding of the tectonostratigraphic evolution of the area during the Lower Jurassic. In addition, this new study will improve the knowledge of the paleogeographical distribution of the Lower Jurassic Foraminifera species in the western Tethys of the eastern Iberian margin, allowing a better comparison with other Tethyan regions.

2 Geological setting

The Jurassic sedimentary successions of Mallorca was deposited in a subsiding basin (Balearic Basin, BB) located in the southeastern margin of the Iberian Plate, in a paleogeographic position adjacent to the Ebro High, which was emerged in those times according to recent paleogeographic reconstructions (Fig. 1) ([Thierry 2000](#); [Scotese and Schettino 2017](#)). The sedimentary evolution of the Balearic basin during the Jurassic accompanied the opening of the Central Atlantic Ocean and the tectonic evolution of the western Tethyan rifting ([Dewey et al. 1973](#); [Dercourt et al. 2000](#)). Although the Balearic archipelago has traditionally been considered as the northeastern prolongation of the Betic Cordillera, new studies suggest that the geodynamic evolution of the area seems to be closer to the early opening of Gulf of Valencia, where recent offshore seismic surveys have brought out the existence of a thick, submerged Mesozoic rift basin, of which, the Balearic archipelago represent the symmetrical southeastern basin

border (Bourrouilh 2016; Etheve et al. 2018). In Mallorca, the biggest island of the archipelago, the rifting evolution during the Jurassic recorded (Álvaro et al. 1989; Barnolas et al. 2010): (1) Lower Jurassic shallow-water carbonate platform successions (Hettangian–Pliensbachian), (2) platform drowning facies during the Toarcian with hardgrounds development, (3) hemipelagic sedimentation during the Toarcian-Aalenian, and (4) typical ammonitico rosso, radiolarites, and mass-wasting deposits indicative of deeper water slope, base of slope and basin environments for the Middle and Upper Jurassic.

The lithostratigraphic subdivision of the Jurassic of Mallorca was established by Álvaro et al. (1989). In particular, the general stratigraphic scheme of the shallow water succession deposited during the Early Jurassic includes (Álvaro et al. 1989; Fig. 3): 1) Hettangian sabkha to restricted platform dolomites of the Mal Pas Formation, 2) Sinemurian to Lower Pliensbachian shallow platform carbonates and siliciclastics of the Soller Formation, and 3) Upper Pliensbachian open platform calcarenites and marly limestones of the Es Cosconar Formation. The Soller Formation is in turn subdivided into three members (Fig. 3): Es Barraca Member, made mainly of shallow water peritidal and lagoonal limestones; Sa Moleta Member, made of outer platform shales-siltstones and marly limestones; and Es Racó Member, constituted by deltaic siliciclastics.

In the Es Barraca Mb, the focus of this study, the previous surveys (Colom 1970; Álvaro et al. 1989) have cited the presence of *Palaeoclasycladus mediterraneus* (Pia), *Thaumatoporella parvovesiculifera* (Raineri), *Lituosepta recoarensis* Cati, and *Orbitopsella praecursor* (Gümbel). In base of the previously micropaleontological data and a deduced stratigraphical lateral relationship with the Sa Moleta Mb (lower Carixian), Álvaro et al. (1989) established the age of the Es Barraca Mb as Sinemurian–Lower Pliensbachian (lower Carixian) (Fig. 3). The Sa Moleta Mb is attributed to the Jamesoni and Ibex ammonite zones of the early Pliensbachian (lower Carixian), based on brachiopods and scarce ammonites fauna (Colom 1942; Álvaro et al. 1989), whereas the Es Racó Mb has been attributed to the upper part of the lower Pliensbachian (upper Carixian).

3 Methods and material

Three stratigraphic sections (Son Maina, S'Heretat and Cuevas de Artà sections) located in the northeast and southeast sectors of Mallorca Island (Llevant Mountains, Fig. 4) have been logged bed-by-bed for the determination of facies and sampling of the Es Barraca Member. The logged facies (F1 to F8 in Fig. 5) consist of limestones and dolostones deposited on tidal flat, subtidal inner platform (including lagoon, internal bars and shoals), muddy open lagoon and muddy outer platform environments, which have been described and reviewed in detail in [Sevillano et al. \(2019\)](#), and therefore, their descriptions are not repeated here. The microfacies description has been made according to the [Dunham \(1962\)](#) nomenclature. Figure 5 shows the detailed lithological logs of the three studied sections with representation of depositional facies and facies associations, along with the stratigraphic location of the studied samples. Notice that the micropaleontological material for this study comes mainly from the subtidal inner platform facies.

The micropaleontological content on foraminifera and other microfossils has been established by the microscopic study of thin sections. A total of 56 thin section samples have been examined. The stratigraphic distribution of the studied samples and the recognized foraminifera and other microfossils are given in Figure 5. The determination of foraminiferal biozones follows the standard biozonation established by [Septfontaine \(1984\)](#), which are widely accepted for the Mediterranean realm. The comparison of this biostratigraphic scheme with other schemes based also on larger benthic foraminifera and with the Lower Jurassic standard ammonite biozones is given in Figure 2.

4 Description of the sections and microfossil assemblages

4.1 Son Maina section

The Son Maina section is located southeast of the Manacor town (coordinates: 39°30'49''N, 3°15'4''E; Fig. 4) in the south of the Llevant Mountains. It crops out in the inverted flank of a NW-SE fold ([Fornós et al. 1984](#)). In this section, the Es Barraca Mb consists of about 219 m of tabular limestones overlaying a succession of dolomites belonging possibly to the Mal Pas Formation (Hettangian). The datum at the top of the succession has been placed in a thin ferruginous crust overlaid by crinoidal limestone of the Cosconar Formation (Fig. 5). It is the most representative of the studied sections, showing the thickest and more complete stratigraphic record. In the first 126.5 m, facies

consist mainly of microbial laminites/stromatolites, flat-pebble breccias and intraclastic-peloidal-oolitic grainstones deposited in peritidal environments (F1, F2 and F3; Fig. 5), interbedded with abundant lime mudstones with scarce restricted fauna (F4) and fossiliferous wackestone-packstone (F6), deposited in shallow restricted and open lagoon environments respectively. Some thin levels of oolitic-peloidal grainstones (F5) representative of internal bars are also present (Sevillano et al. 2019). The succession evolves upward, in the following 88 m (up to meter 214.5), to a predominance of skeletal mudstone-wackestone (F6, F8), peloidal-oncolitic-foraminiferal wackestone-packstone (F6, F7) and oolitic-oncolitic grainstones (F5), interpreted as subtidal facies. They are interbedded with a minor amount of fenestral mudstones deposited in peritidal environments (F2), which are noticeably less developed in this upper part of the succession (Fig. 5). This interval ends with the development of a thin ferruginous hardground surface (HG-0 in Fig.4). Above this hardground (HG-0), from meter 214.5 to 219, the facies consist mainly of silty, peloidal-oolitic packstone to grainstone containing larger Foraminifera and large coarse oncoids, suggesting still deposition in a shallow protected carbonate shelf. This interval finishes also with the development of an irregular ferruginous hardground surface (HG-1 in Fig. 5) containing pockets of rounded, centimetric quartzite pebbles on top, suggesting the by-pass of coarse siliciclastics. Above this hardground surface at the meter 219 (HG-1, Fig. 5), the succession follows with a highly covered interval of grainstones rich in echinoderm remains, containing also some internal ferruginous hardgrounds with ammonites and belemnites, deposited in an open shelf and attributed already to the upper Pliensbachian Es Cosconar Fm (Fig. 5).

The observed microfossil assemblage (Figs. 5–7) contains, throughout the whole Es Barraca Mb, abundant representatives of *Palaeoclasycladus mediterraneus* (Pia) and *Thaumatoporella parvovesiculifera* (Raineri). In the first 106 m of the section, the Foraminifera assemblage includes: *Siphovalvulina*, *Siphovalvulina* evolved to primitive *Pseudofenderina* and transition to *Valvulina*, *Valvulina*, *Pseudofenderina*, *Everticyclammina praevirguliana* Fugagnoli, *Meandrovoluta asiagoensis* Fugagnoli & Rettori, *Duotaxis*, *Biokovina*, *Mesoendothyra*, evolved uncoiled *Mesoendothyra* with important planispiral nepionic stage, and some ancestor of *Lituosepta*. The later are uncoiled cylindrical Mesoendothyrids, very small forms, with no internal subdivisions. The first occurrence of *Lituosepta recoarensis* Cati occurs at the meter 106 and it is

recorded upward for rest the succession along with *Siphovalvulina-Valvulina*, *Everticyclammina* and *Mesoendothyra*. Approximately 160 m from the base of the succession begin to appear abundant flat morphotypes of *Planisepta* (Fig. 7i) along with less common *Haurania deserta* Henson (Fig. 7g). The first appearance of primitive forms of *Orbitopsella* occurs in the upper part of the succession, from meter 196 to 202, showing this interval a good transition of *Lituosepta* to *Orbitopsella*, with small size (2–3 mm) flabelliform to reniform tests but no true discoid. The first occurrence of *Orbitopsella primaeva* (Henson) occurs at meter 202 (small diameter 4–5 mm), along with cylindrical *Lituosepta recoarensis* Cati and flat *Planisepta*, *Siphovalvulina* and uncoiled *Mesoendothyra*. The last interval of the succession, between hardgrounds HG-0 and HG-1 (meters 214.5 to 219, Fig. 5), contains *Orbitopsella primaeva* (Henson), *Everticyclammina* sp. *Siphovalvulina* (thick wall) and *Valvulina*. From meter 219, above the hardground surface HG-1 (Fig. 5), the microfacies change to sandy crinoidal packstone with Lagenids (open marine benthic Foraminifera) but not larger complex Foraminifera, indicating an abrupt change to open marine conditions (Es Cosconar Fm).

4.2 S'Heretat section

The S'Heretat section is located east of the Artà town (coordinates: 39°40'47''N, 3°25'55''E; Fig. 4) and is 131.5 m thick. Its lower boundary with the Mal Pas Formation is not exposed, whereas the top boundary is an unconformably contact with the crinoidal limestone of the Es Cosconar Formation. The first 45 m of the succession are composed mainly of microbial laminites and laminated stromatolites (F2) deposited in peritidal environments, alternating with less abundant lime mudstones with scarce fauna (F4) and oolitic-peloidal grainstones (F5) interpreted to be deposited in subtidal restricted lagoons and internal bars respectively (Sevillano et al. 2019; Fig. 5). Above meter 45 and up to metre 106, the deposits are dominated by subtidal facies made of skeletal mudstone-wackestone and peloidal-oncolitic wackestone-packstone with abundant foraminifera (F6–F8), deposited in shallow open lagoons to open platform environments, interbedded with subordinated oolitic-peloidal-oncolitic grainstones (F5) deposited in internal bars and shoals (Sevillano et al. 2019; Fig. 5). In this interval, some few thin intercalations of peritidal microbial laminites (F2) also occur. Finally, from meter 106 up to 131.5, the succession follows with oolitic-peloidal-oncolitic grainstones (F5) alternating with peloidal-oncolitic-foraminiferal wackestone (F6) deposited in subtidal inner platform environments (Fig. 5). In this interval, only one thin

intercalation of peritidal laminites with flat pebbles (F1) is present approximately at meter 114. Above this interval the succession follows with an interval of grainstones rich in echinoderm remains attributed to the Pliensbachian Es Cosconar Fm (Fig. 5).

The microbial-dominated lower part of the succession (up to meter 45) shows very scarce microfossils. In samples from some basal grainy layers *Palaeoclasycladus mediterraneus* (Pia) has been identified. From meter 46 upward, the microfossil assemblage is notably more diversified and includes: *Siphovalvulina*, *Siphovalvulina* to *Pseudofenderina* transition, *Mesoendothyra*, *Everticyclammina* sp. (Fig. 6o), *Lituosepta recoarensis* Cati (Fig. 7f), *Palaeoclasycladus mediterraneus* (Pia) and *Thaumatoporella parvovesiculifera* (Raineri). From meter 87 upward begin to appear also flat morphotypes of *Planisepta* along with evolved flabelliform forms of *Lituosepta recoarensis* Cati, varied forms of *Siphovalvulina*, and evolved *Mesoendothyra*. This assemblage is observed up to metre 131.5. From meter 131.5 upwards, the microfacies change sharply to crinoidal wackestone-packstone with bryozoan and Lagenids, but no complex larger Foraminifera, reflecting an abrupt change to completely different open shelf conditions (Es Cosconar Fm).

4.3 Cuevas de Artà section

The Cuevas de Artà section locates close to the Cap Vermell (coordinates: 39°39'55''N, 3°27'8'' E; Fig. 4). At this locality, the measured thickness of the Es Barraca Member is 110 m. The lower datum is the contact with a basal dolomite body attributed to the Hettangian (Mal Pas Formation). The top boundary is an unconformity represented by a ferruginous hardground, which is overlaid by red nodular limestone with pelagic thin-shelled bivalves attributed to *Bositra*, and ammonites of Bajocian age (Álvaro et al. 1989). Therefore, at this locality, a hiatus spanning at least from the Pliensbachian to the Bajocian is implied. The whole succession is made of peritidal deposits mainly, consisting of an alternation of black-pebble conglomerates (F1), microbial laminites-stromatolites (F2), intraclastic-peloidal-oolitic grainstones with pedogenic features (F3) deposited in intertidal-supratidal environments, and lime mudstone (F4) deposited in restricted lagoons (Fig. 5). Some few thin oolitic grainstone intercalations (F5), interpreted as internal bars, are also present.

The Cuevas de Artà section shows a low-diversified microfossil assemblage, lacking larger foraminifera. It includes abundant *Palaeodasycladus mediterraneus* (Pia) and *Thaumatoporella parvovesiculifera* (Raineri), along with specimens of *Siphovalvulina* and *Mesoendothyra*.

5 Discussion

5.1 Biostratigraphy and age constraints of the Es Barraca Mb

As a general consideration, all of the analysed samples from the three studied sections show microfacies indicative of shallow, lagoonal, inner platform environments, except in two samples belonging to the Es Cosconar Formation, at the top of the Son Maina and S'Hereat sections (Fig. 5), which represent a completely different environment rich in echinoderm remains and Lagenids, indicative of open marine conditions. For the rest of the samples, the small particles are made mainly of microolites or microncoids, which are omnipresent. Other particles are bioclasts, muddy lithoclasts (peloids), benthic Foraminifera, algae, calcimicrobes and large oncoids. The dasycladacean algae *Palaeodasycladus* occurs throughout all the studied sections associated with the microproblematic *Thaumatoporella*, both typifying the Liassic protected interior seas of the western Tethys (e.g. [BouDagher-Fadel et al. 2001](#)). The widespread occurrence of these genera in the western Tethys was favoured by the continuity of the shallow carbonate platform environments along the whole region. The genus *Palaeodasycladus* was confined to the Lower and Middle Lias (Hettangian to Pliensbachian), whereas the genus *Thaumatoporella* had a much longer stratigraphic range.

After the pioneer studies of Colom in the past century ([Colom 1966, 1970, 1980, Colom and Dufaure 1962](#)), there are not other studies about the biostratigraphy of the Lower Jurassic shallow water successions of the Balearic Islands. However, these authors did not identify benthic foraminiferal assemblages and biozones in these successions. There are, for the Early Jurassic, several biostratigraphic schemes, based on benthic larger Foraminifera. In this study, the chronobiostratigraphic proposal of [Septfontaine \(1984\)](#) has been adopted for the characterization of the Foraminifera zonal scheme of the studied successions. The comparison of this scheme for the Sinemurian–Pliensbachian

289 with other proposed benthic foraminiferal biostratigraphic schemes and with the
290 standard ammonite zones is shown in Figure 2.

291 The analysed samples of the Es Barraca Mb show that larger Foraminifera were diverse
292 in the Balearic region, showing assemblages comparable with others reported from
293 southern Iberia and Morocco (Septfontaine 1984, Azerêdo et al. 2003, BouDagher-
294 Fadel and Bosence 2007). According to the observed Foraminifera assemblages, the
295 three biozones A, B and C1 have been identified (Fig. 8). These biozones could be
296 correlated with those proposed by Septfontaine (1984) for the Lower Jurassic of the
297 High Atlas of Morocco, although there is a modification due to the presence of an
298 interval of transition between biozone B and C1 (Fig. 8). The biostratigraphy and the
299 chronostratigraphic interpretation of the studied successions are shown in Figure 8. The
300 Es Barraca Mb corresponds mainly to biozones A, B and B/C1 transition, the later
301 observed only in the uppermost part of the unit in the Son Maina section (Fig. 8).

302 The biozone A (*Siphovalvulina* sp. and *Mesoendothyra* sp. Interval Zone) has been
303 identified in the three studied sections. This biozone is characterized by the presence of
304 *Siphovalvulina* and *Mesoendothyra* along with some *Lituosepta* ancestors. The upper
305 boundary of this biozone is marked by the first occurrence of *Lituosepta recoarensis*
306 Cati. In the Son Maina section, the most complete of the three, the biozone A spans
307 from the base of the section up to meter 106. In the S'Heretat section, biozone A spans
308 up to meter 46. In the Cuevas de Artà section, all the succession of the Es Barraca Mb
309 up to the hardground overlaying the shallow water limestones corresponds to biozone
310 A.

311 The biozone B (*Lituosepta recoarensis* Lineage Zone) is defined by Septfontaine (1984)
312 as a phylozone spanning from the first occurrence of *Lituosepta recoarensis* Cati up to
313 the first occurrence of *Orbitopsella primaeva* (Henson). In the Son Maina section, this
314 biozone starts at meter 106 and spans up to meter 196, where the first primitive forms of
315 *Orbitopsella* appear. In this biozone *Lituosepta recoarensis* co-occurs with
316 *Siphovalvulina* and *Mesoendothyra* persisting from the underlying biozone. In the upper
317 part of the biozone flat morphotypes of *Planisepta* and *Haurania deserta* also occur. In
318 the S'Heretat section, biozone B starts at meter 46 and spans up to the hardground at top
319 of the succession of the Es Barraca Mb, since here *Orbitopsella* specimens have not
320 been found. In the Cuevas de Artà section, biozone B is absent (Fig. 8).

321 In the Son Maina section the top of the Es Barraca Mb is represented by the hardground
 322 surface HG-0 (Fig. 8). Below this hardground surface, the meters 196 to 214
 323 (uppermost part of the Es Barraca Mb) are characterized by only small primitive forms
 324 of *Orbitopsella*, suggesting a transitional zone between biozones B and C1 (biozone
 325 B/C1 transition in Fig. 8) for this part of the succession, and therefore, for the
 326 uppermost Es Barraca Mb (Fig. 8). The biozone C1 (*Orbitopsella primaeva* Lineage
 327 Zone) is present only in the uppermost part of the Son Maina section, above the
 328 hardground surface HG-0 which marks the top of the Es Barraca Mb (Fig. 8).

329 [BouDagher-Fadel and Bosence \(2007\)](#) set the first appearance of *Everticyclammina*
 330 *praevirguliana* in the middle Sinemurian for the western Mediterranean region, whereas
 331 according to [Velić \(2007\)](#) it appears already in the late Hettangian. There is a better
 332 consensus with the first appearance of *Lituosepta recoarensis* in the late Sinemurian
 333 ([Septfontaine 1984](#), [BouDagher-Fadel and Bosence 2007](#), [Velić 2007](#)), having this
 334 species a relative well-defined biostratigraphic position in this part of the stage. The
 335 first occurrence of *Orbitopsella* is established in the latest Sinemurian, with *O.*
 336 *primaeva* spanning from the latest Sinemurian to the early Pliensbachian ([Septfontaine](#)
 337 [1984](#), [Velić 2007](#)). According to these data, it can be concluded that the Es Barraca Mb
 338 of Mallorca has a Sinemurian age (probably middle–late Sinemurian), biozones A–B.
 339 At Son Maina, the most complete section, the uppermost part of the Es Barraca Mb (the
 340 last 16 m below the hardground surface HG-0) would correspond to the upper part of
 341 the late Sinemurian showing a transition between biozones B/C1. This suggests an age
 342 not younger than the late Sinemurian for the top of the Es Barraca Mb, implying,
 343 therefore, that the top of the Es Barraca Mb did not reach the Pliensbachian, as it has
 344 been suggested in earlier studies ([Álvaro et al. 1989](#)) (Fig. 9). The interval of shallow-
 345 water limestones containing *Orbitopsella* aff. *primaeva* between the hardgrounds HG-0
 346 and HG-1 (meters 214.5 to 219, Figs. 5, 8) could range in age from the latest
 347 Sinemurian to the early Pliensbachian (early Carixian), biozone C1. The first
 348 *Orbitopsella* aff. *primaeva* that appear in this interval are very small (diam. 4–6 mm)
 349 and primitive compared to the typical *O. primaeva* (10–15 mm) and are also scarce,
 350 which points to preferably latest Sinemurian age. However, the absence of more
 351 complex and evolved larger Orbitopsellids in these beds could be in part biased by
 352 sorting effects in the carbonate sands (absence of larger particles), implying, therefore,

that an early Pliensbachian age cannot be totally excluded for this interval. More information of this interval in other sections is needed.

5.2 Evolutionary considerations

The Jurassic litoiids underwent significant evolutionary changes during the Sinemurian. The most important is the evolution of most of the Early Jurassic litoiids from *Mesoendothyra* sp. (Septfontaine 1984, 1988). One of the proposed evolutionary lines evolving from this form in the late Sinemurian resulted in the Orbitopsellids following this changes: *Mesoendothyra* sp. – *Lituosepta recoarensis* – *Orbitopsella primaeva* – *O. praecursor* (Septfontaine 1984, 1988). In the studied samples, this gradual evolution of the Orbitopsellids s.l. during the Sinemurian could be observed in three steps (step 1 to 3 in Fig. 8), which represent evolutionary relatively stable morphogenetic (architectural) innovations in a “population genetic” setting with many transitions, as observed in the Son Maina section. The biozonation proposed in this study is based on these steps (phylozones), and their equivalence with the biozones is shown in figure 8.

In the Son Maina and S’Heretat sections, the evolutionary steps are observed as follows: Step 1, meters 24–106, characterized by *Lituosepta* ancestor (uncoiled cylindrical Mesoendothyrids), with no internal subdivisions, important plani nepionic stage, and very small forms. Step 2, meters 106–161, characterized by the first apparition of vertical radial partitions, true cylindrical *Lituosepta recoarensis* with rare flat “Planisepta-like” types. Step 3, meters 161–214.5, characterized by the diversification of the shape and external contour of the test with internal complications. With advanced *Lituosepta* to *Orbitopsella* with reniform to discoidal test and internal complications. The flat morphotypes “Planisepta-like” become frequent. It is observed many transitions between the different morphotypes but with a general trend to increase the chamber volume for hosting symbionts. To go further in the mode of evolution, more data from bed-by bed sampling are needed.

5.3 Stratigraphic implications

6 Conclusions

383

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387

388 **References**

- 389 Álvaro M., Barnolas A., Cabra P., Comas-Rengifo M.J., Fernández-López S.R., Goy
390 A., Del Olmo P., Ramírez del Pozo J., Simo A., Ureta S. (1989). El Jurásico de
391 Mallorca (Islas Baleares). *Cuadernos de Geología Ibérica*, 13, 67–120.
- 392 Barnolas A., Simó J.A., Rosales I., Gil-Peña I., Sevillano A., Armendáriz M. (2010).
393 Revisión de la información paleogeográfica del Jurásico de Mallorca basada en datos
394 sedimentológicos y en el análisis de cuenca. In J.I. Ruiz-Omeñaca, I. Piñuea, J.C. García-
395 Ramos (Eds). *Comunicaciones del V Congreso del Jurásico de España*. Museo del
396 Jurásico de Asturias, pp 163.
- 397 Boudagher-Fadel M.K., Bosence, D.W.J. (2007). Early Jurassic benthic foraminiferal
398 diversification and biozones in shallow-marine carbonates of western Tethys.
399 *Senckenbergiana Lethaea*, 87, 1–39.
- 400 Bourrouilh, R. (2016). The Balearic Islands in the Alpine Orogeny. *Boletín Geológico y*
401 *Minero*, 127(2/3), 527-546.
- 402 Colom, G. (1942). Sobre nuevos hallazgos de yacimientos fosilíferos del Lias medio y
403 superior en la Sierra Norte de Mallorca. *Boletín de la Real Sociedad Española de*
404 *Historia Natural*, 11, 221–265.
- 405 Colom, G. (1966). Dos niveles micropaleontológicos interesantes en el Lias inferior del
406 Sur de España y baleares. *Acta Geologica Hispanica*, 1(3), 15–18.
- 407 Colom, G. (1970). Estudio litológico y micropaleontológico del Lías de la Sierra Norte
408 y porción central de la isla de Mallorca. *Memorias de la Real Academia de la Ciencias*
409 *exactas, físicas y naturales de Madrid*, Tomo XXIV, Mem 2.

- 410 Colom, G., Dufaure, P. (1962). Présence de la zone à *Palaeodasycladus mediterraneus*
 411 (Pia) dans le Lias moye du Pla de Cuber (Majorque). *Comptes Rendus de l'Académie*
 412 *des Sciences Paris*, 12, 2617–2619.
- 413 Dercourt, J., Gaetani, M., Vrielynck, B., Barrier, E., Bijou-Duval. B., Brunet, M.F.,
 414 Cadet, J.P., Crasquin, S., Sandulescu, M. (Eds) (2000), *Atlas Peri-Tethys*,
 415 *Palaeogeographical maps, I–XX*, CCGM/CGMW, Paris.
- 416 Dewey, J.F., Pitman, W.C., Ryan, W.B.F., Bonnin, J. (1973). Plate tectonics and the
 417 evolution of the Alpine system. *Geological Society of America Bulletin*, 84, 3137–3180.
- 418 Dunham, R.J. (1962). Classification of carbonate rocks according to depositional texture.
 419 In Classification of carbonate rocks. W.E. Ham (Ed), AAPG Mem 1 (pp. 108–121).
- 420 Etheve, N., Mohn, G., Frizon de Lamotte, D., Roca, E., Tugend, J., Gómez-Romeu, J.,
 421 (2018). Extreme Mesozoic Crustal Thinning in the Eastern Iberia Margin: The Example
 422 of the Columbrets Basin (Valencia Trough). *Tectonics*, 37(2), 1–27.
- 423 Fallot, P. (1922). Étude géologique de la sierra de Majorque. Thèse d'état. Libr.
 424 Polytechnique Ch. Béranger, Paris i Liège.
- 425 Franceschi, M., Dal Corso, J., Cobianchi, M., Roghi, G., Penasa, L., Picotti, V., Preto, N.
 426 (2019). Tethyan carbonate platform transformation during the Early Jurassic (Sinemurian–
 427 Pliensbachian, Southern Alps): Comparison with the Late Triassic Carnian Pluvial
 428 Episode. *Geological Society of America Bulletin*, 131, 1255–1275.
- 429 Fugagnoli, A., Loriga Broglio, C. (1998). Revised biostratigraphy of Lower Jurassic
 430 shallow water carbonates from the Venetian Prealps (Calcarei Grigi, Trento Platform,
 431 Northern Italy). *Studi Trentini di Scienze Naturali - Acta Geologica*, 73, 35–73.
- 432 Fornós, J., Rodríguez-Perea, A., Sabat, F. (1984). El mesozoico de la Serra de Son
 433 Amoixa (Serres de Llevant, Mallorca). *I Congreso Español de Geología*. Tomo 1, pp
 434 173–185.
- 435 Gale, L. (2014). Lower Jurassic foraminiferal biostratigraphy of Podpeč Limestone
 436 (External Dinarides, Slovenia). *Geologija*, 57, 119–146.
- 437 Kabal, Y., Tasli, K. (2003). Biostratigraphy of the Lower Jurassic carbonates from the
 438 Aydinick area (Central Taurides, S. Turkey) and morphological analysis of *Lituolipora*
 439 *Termieri* (Hottinger, 1967). *Journal of Foraminiferal Research*, 33, 338–351.

- 440 Mancinelli, A., Chiocchini, M., Chiocchini, R.A, Romano, A. (2005). Biostratigraphy of
 441 Upper Triassic-Lower Jurassic carbonate platform sediments of the central-southern
 442 Apennines (Italy). *Rivista Italiana di Paleontologia e Stratigrafia*, 111, 271–283.
- 443 Masetti, D., Figus, B., Jenkyns, H.C., Barattolo, F., Mattioli, E., Posenato, R. (2017).
 444 Carbon-isotope anomalies and demise of carbonate platforms in the Sinemurian (Early
 445 Jurassic) of the Tethyan region: evidence from the Southern Alps (Northern Italy).
 446 *Geological Magazine*, 154, 625–650.
- 447 Preto, N., Breda, A., Dal Corso, J., Franceschi, M., Rocca, F., Spada, C., Roghi, G. (2017).
 448 The Loppio Oolitic Limestone (Early Jurassic, Southern Alps): A prograding oolitic body
 449 with high original porosity originated by a carbonate platform crisis and recovery. *Marine*
 450 *Petroleum Geology*, 79, 394–411.
- 451 Rosales, I., Barnolas, A., Goy, A., Sevillano, A., Armendáriz, M., López-García, J.M.
 452 (2018). Isotope records (C-O-Sr) of late Pliensbachian-early Toarcian environmental
 453 perturbations in the westernmost Tethys (Majorca Island, Spain). *Palaeogeography*
 454 *Palaeoclimatology Palaeoecology*, 497, 168–185.
- 455 Ruiz-Ortiz, P.A., Bosence, D.W., Rey, J., Nieto, L.M.; Castro, J.M., Molina, J.M.
 456 (2004). Tectonic control of facies architecture, sequence stratigraphy and drowning of a
 457 Liassic carbonate platform (Betic Cordillera, Southern Spain). *Basin Research*, 16, 235–
 458 257.
- 459 Rychliński, T., Uchman, A., Gaździcki, A. (2018). Lower Jurassic Bahamian-type
 460 facies in the Choč Nappe (Tatra Mts, West Carpathians, Poland) influenced by
 461 palaeocirculation in the Western Tethys. *Facies*, 64, 15.
- 462 Sevillano, A., Rosales, I., Bádenas, B., Barnolas, A., López-García J.M. (2019). Spatial
 463 and temporal facies evolution of a Lower Jurassic carbonate platform, NW Tethyan
 464 margin (Mallorca, Spain). *Facies*, <https://doi.org/10.1007/s10347-018-0545-0>.
- 465 Scotese, C.R., Schettino, A. (2017). Late Permian-Early Jurassic Paleogeography of
 466 Western Tethys and the World. In: *Permo-Triassic Salt Provinces of Europe, North*
 467 *Africa and the Atlantic Margins*. Elsevier, pp 57–95.
- 468 Septfontaine, M. (1984). Biozonation (a l'aide des Foraminifères imperforés) de la
 469 plate-forme interne carbonatée liasique du Haut Atlas (Maroc). *Revue de*

470 *Micropaléontologie*, 27, 209–229.

471 Septfontaine, M. (1988). Vers une classification évolutive des lituolidés (Foraminifères)
 472 jurassiques en milieu de plate-forme carbonatée. *Revue Paléobiologie* Vol Spec 2,
 473 Benthos'86, pp. 229–256.

474 Thierry, J. (2000). Late Sinemurian (193–191 Ma). In: J. Dercourt, M. Gaetani, B.
 475 Vrielynck, E. Barrier, B. Biji-Dubal, M.F. Brunet, J.P. Cadet, S. Crasquin, M.
 476 Sandulescu (Eds), *Atlas Peri-Tethys*. Palaeogeographical Maps explanatory notes.
 477 Commission for the Geologic Map of the World, Paris, pp 49–59.

478 Velić, I. (2007). Stratigraphy and palaeobiogeography of Mesozoic benthic foraminifera
 479 of the Karst Dinarides (SE Europe). *Geologia Croatica*, 60, 1–113.

480 Zempolich, W.G., (1993). The drowning succession in Jurassic carbonates of the
 481 Venetian Alps, Italy, a record of supercontinent breakup, gradual eustatic rise, and
 482 eutrophication of shallow water environments. In: R.G. Loucks, J.F. Sarg (Eds.),
 483 *Carbonate Sequence Stratigraphy: Recent Developments and Applications*. AAPG
 484 Memoir, 57 (pp. 63– 105).

485

486 **Figure captions**

487 **Figure 1:** Palaeogeographical map of the western Tethys for the Sinemurian-earliest
 488 Pliensbachian (modified from [Dercourt et al. 2000](#)) showing the palaeogeographical
 489 location of the study area. Yellow star: Location of this study area (BB: Balearic Basin).
 490 Red dots: Location of other neighbouring basins (HA: High Atlas; IbR: Iberian Range;
 491 BC: Betic Cordillera; ApCP: Appennine carbonate platform; DiCP: Dinaric carbonate
 492 platform).

493 **Figure 2:** Comparison between the standard ammonites biozones and various benthic
 494 foraminiferal biostratigraphic schemes for the Sinemurian–Pliensbachian interval
 495 proposed for different carbonate platforms of the Western Tethys.

496 **Figure 3:** General chronostratigraphic chart of the Lower Jurassic of Mallorca with
 497 indication of the defined lithostratigraphic units. Modified from [Álvaro et al. \(1989\)](#).

498 **Figure 4:** Simplified geological map of Mallorca with the location of the three studied
499 stratigraphic sections. The distances between stratigraphic sections (SH: S’Heretat; CA:
500 Cuevas de Artá; MAI: Son Maina) are shown as today, without restoring the tectonic
501 shortening.

502 **Figure 5:** Detailed stratigraphic logs of the Es Barraca Mb in the Son Maina, S’Heretat
503 and Cuevas de Artà sections, with location of the studied samples, distribution of
504 benthic foraminifera and algae, and interpretation of the facies associations and facies
505 types (F1 to F8).

506 **Figure 6:** Pictures of representative microfossils from the studied sections. **a**
507 *Palaeodasycladus mediterraneus* (Pia). **b** *Palaeodasycladus mediterraneus* (Pia)
508 (yellow arrow) and lituolids (red arrow) **c** *Palaeodasycladus mediterraneus* (Pia). **d–f**
509 *Thaumatoporella parvovesiculifera* (Raineri). **g–i** *Siphovalvulina* sp. **j–m**
510 *Mesoendothyra* sp. **n–o** *Everticyclammina praevirguliana* Fugagnoli. **p** *Duotaxis* sp.

511 **Figure 7:** Pictures of representative microfossils from the studied sections. **a** *Biokovina*
512 sp. **b–f** *Lituosepta recoarensis* Cati. **g** *Haurania deserta* Henson. **h** *Haurania* sp. (red
513 arrow) and *Lituosepta recoarensis* Cati (yellow arrow). **i–j** *Planisepta* morphotype
514 (yellow arrow). **k–m** *Orbitopsella* aff. *primaeva* Henson. **n** *Meandrovoluta asiagoensis*
515 Fugagnoli & Rettori.

516 **Figure 8:** Distribution of benthic foraminiferal biozones of the Es Barraca Mb in the
517 Son Maina, S’Heretat and Cuevas de Artà sections (Llevant Mountains domain,
518 Mallorca), based on the biozonation scheme proposed by [Sepfontaine \(1984\)](#). The steps
519 1 to 3 (phylozones) represent evolutionary stages of the larger lituolids based on
520 morphological transitions from Mesoendothyrids to Orbitopsellids s.l.

521 **Figure 9 ... ???**

522

DEPOSITIONAL ENVIRONMENTS:

Exposed landmasses	Coastal marine, shallow marine (terrigenous)
Fluvial, lacustrine, fluvio-lacustrine	Epicontinental platforms
Hypersaline	Deep marine and oceanic basins
Shallow environments with fluctuating salinities	

- ★ **BB (Balearic Basin)**. This study
 ↑ **HA (High Atlas)**
 ● **IbR (Iberian Range)**
 ● **BC (Betic Cordillera)**
 ↓ **ApCP (Appennine Carbonate Platform)**
 ↓ **DiCP (Dinaric Carbonate Platform)**

PLIENSBACHIAN	spinatum	E <i>Pseudocyclammina liassica</i>	<i>L. termieri</i>	<i>P. liassica</i>	
	margaritatus	D <i>Paleomayncina termieri</i> and <i>Planisepta compressa</i>		<i>O. praecursor</i> - <i>P. liassica</i>	
	davoei	C2 <i>Orbitopsella praecursor</i>		<i>O. praecursor</i>	
	ibex	C1 <i>Orbitopsella primaeva</i>	<i>O. primaeva</i>	<i>O. primaeva</i>	<i>L. compressa</i>
	jamesoni				
SINEMURIAN	raricostatum	B <i>Lituosepta recoarensis</i>	<i>L. recoarensis</i>		<i>L. recoarensis</i> & <i>Orbitopsella</i> spp.
	oxynotum			<i>L. recoarensis</i>	
	obtusum	A <i>Siphovalvulina</i> sp. and <i>Mesoendothyra</i> sp.		<i>Mesoendothyra</i>	<i>E. praevirguliana</i>
	turneri				<i>S. colomi</i>
	semicostatum				
	bucklandi				
		Septfontaine (1984)	Kabal & Tasli (2000)	Velic (2007), Gale (2014)	BouDagher-Fadel & Bosence (2007)
		<i>High Atlas (Morocco)</i>	<i>Central Taurides (Turkey)</i>	<i>Adriatic Carbonate Platform (Slovenia-Croatia)</i>	<i>Betics and Iberian Basin (Spain); Gibraltar; Tunisia; Greece; Italy.</i>