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RESEARCH PAPER

Early Toarcian (Jurassic) brachiopods from the Balearic Islands (Spain) and their paleobiogeographic context

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Abstract
The record of brachiopods in the Lower Toarcian of the Balearic Islands is described after a reassessment of previous works and new samplings in the Tramuntana Range of Mallorca. The recognized species have been assimilated to the assemblages described in the Iberian Range in the Tenuicostatum and Serpentinum biozones. Moreover, a detailed comparison with other Western Tethys basins and the study of the dispersion of the brachiopod faunas in relation with the Early Toarcian Oceanic Anoxic Event, allow to refine the paleobiogeographic relationship of the Balearic brachiopods. They belong to the Euro-Boreal Province of brachiopods in the Tenuicostatum Biochron and correspond to the”Spanish Fauna” that emerged after the deep paleobiogeographic disruption that took place at the base of Serpentinum Biochron. The occurrence of *Prionorhynchia msougari* Rousselle in the Serpentinum Zone of Mallorca indicates that, within this last assemblage, there would be a closer connection between the Balearic region and the southern margin of the Tethys (Betic and North African basins) than with the northern margin (Eastern Iberian Platform System and Eastern Pyrenees). This paleobiogeographic conclusion is consistent with the supposed position of the Balearic area in the Early Toarcian, on the southeastern margin of Iberia and near the Alboran and Kabylian margins.

Keywords Brachiopods · Biostratigraphy · Paleobiogeography · Early Jurassic · Mass extinction · Western Tethys

1 Introduction

The paleogeographic position of the Balearic Islands in the Early Jurassic has been a matter of discussion for the last decades (Olóriz et al., 2002; Sevillano et al., 2019, 2021). Based on their structural characteristics, they have been viewed classically as the northeastern prolongation of the Betic Cordillera (Fourcade et al., 1977; Guerrera et al., 1993), although more recently other authors consider its paleogeographic evolution more related to the tectonic opening of the Gulf of Valencia and the Corsica-Sardinia rotation (cf, Bourrouilh, 2016), being the Balearic Islands its symmetrical image with respect to this opening. From a paleontological point of view, there seems to be a close relationship of the Balearic Islands to the Catalonian region in the Paleozoic and the Triassic (Meléndez et al., 1988) and its Lower Jurassic ammonite assemblages are more related to those recorded in NW Europe than to the typical Mediterranean Betic faunas (Álvaro et al., 1989). The paleogeography of this area is of special relevance in the Toarcian, when the opening of the Central Atlantic Ocean led to a period of paleogeographic reorganization. The distribution of the fauna is also considerably altered at this time, with important extinctions and biotic changes that mainly affected the benthic and nektonic-planktonic marine biomes (Arias et al., 1992; Caruthers et al., 2013; Danise et al., 2013, 2015; Gómez & Goy, 2011; Hallam, 1986, 1987; Harries & Little, 1999; Little & Benton, 1995; Reolid & Ainsworth, 2022; Ruebsam et al., 2018; Wignall et al., 2005). Concerning brachiopods, this event represented one of the most relevant extinctions of their post-Paleozoic history, with the fading away of two orders,

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Spiriferinida and Athyridida (Baeza-Carratalá et al., 2015; García Joral et al., 2011; Vörös, 2002; Vörös et al., 2019). One of the consequences of this crisis is the disruption of the established provinciality and the mixing of faunas (Baeza-Carratalá, 2013; Baeza-Carratalá et al., 2018; Dera et al., 2010; García Joral et al., 2011; Macchioni & Cecca, 2002; Martínez & García Joral, 2020).

Brachiopods are a very suitable group for detailed paleobiogeographic studies, because of its abundant and continuous record and its short larval stage (at least in post-Paleozoic times) implying a slow dispersal strongly influenced by physical barriers. In the Jurassic, this group has been often used in paleobiogeographic analysis, mainly referred to Western Tethys (Ager, 1967, 1971, 1973; Baeza-Carratalá & Sepehriannasab, 2014; Manceñido, 2002; Radulović et al., 2016; Ruban & Vörös, 2015; Vörös, 1977, 1980, 2016; Vörös & Escarguel, 2019). Although scarcely represented in the Lower Jurassic of Balearic Islands, the occurrence of Toarcian brachiopods in northern Menorca and in the Tramuntana Range of Mallorca (Fig. 1) allows its comparison with other well-known assemblages throughout Western Tethys.

In Menorca, the Lower Jurassic sedimentation is predominantly dolomitic, and brachiopods are constrained to a single marly tract in the locality of Cap de Fornells described by Llompart (1979). This author (with the collaboration of M.J. Comas-Rengifo & A. Goy) identified and figured 15 species from these levels (the authors and dates of all the species cited in the text can be consulted in a Systematic Annex at the end of this article): *Stolmorhynchia bouchardi*, *Homoeorhynchia meridionalis*, *H. batalleri*, *"Rhynchonella"* aff. *vasconcellosi*, *"Rhynchonella"* sp. 1, *"R."* sp. 2, *"Terebratula" jauberti*, *"T." jauberti* var. *pyrenaica*, *"T." jauberti* var. *leymeriei*, *"T." perfida*, *"T."* aff. *witnichi*, *"T."* sp. 1, *"T."* sp. 2, *"T."* sp. 3 and *"T."* sp. 4. These species have been reviewed and their taxonomy updated (Appendix A).

In Mallorca, the outcrops of Lower Jurassic rocks in expanded series are very scarce. Only a few outcrops in the Tramuntana Range are known where ammonoids and brachiopods have been cited. One of these outcrops is the Es Cosconar (Escorca) site, studied in the last decades of the XIX century and the first third of the XX century by Nolan (1893, 1895) and Fallot (1914, 1922, 1932). Later, Colom (1942) collected numerous fossils of Mollusks and Brachiopods from this area, in a ravine cut by the Pareis stream, close to the Cosconar wellspring and the cottage with the same name. Among the brachiopods this author identified: *Terebratula jauberti*, *T. jauberti* var. *pyrenaica*, *T. jauberti* var. *leymeriei*, *T. decipiens*, *Zeilleria* cf. *subdigona*, *Rhynchonella ranina*, *Rh.* aff. *curviceps*, *Rh. meridionalis*, *Rh.* aff. *linki*, *Rh. bouchardi*, *Rh. bouchardi* var. aff. *penichensis*, *Rh. bouchardi* var. *rustica*, *Rh. dumbletonensis* var. *attenuata* and *Rh. batalleri* (typical Pyrenean race). As in the case of the Menorca assemblages, these identifications have been taxonomically updated in Appendix A.

The aim of this paper is to characterize the assemblages of Lower Toarcian brachiopods of both islands, as a contribution to elucidate their paleobiogeographic connections with other Western Tethys areas in the Early Jurassic. For this purpose, besides the taxonomical updating of the species identified by Colom (1942) and Llompart (1979), the section of Es Cosconar has been sampled again in detail and fossils (ammonoids and brachiopods) have been obtained from the materials of the Tenuicostatum and Serpentinum zones of the standard scale (Rosales et al., 2018).

2 Stratigraphic framework

The chronostratigraphic framework of the Lower and Middle Toarcian of the Tramuntana Range of Mallorca has been established in previous works (Álvaro et al., 1989; Olóriz

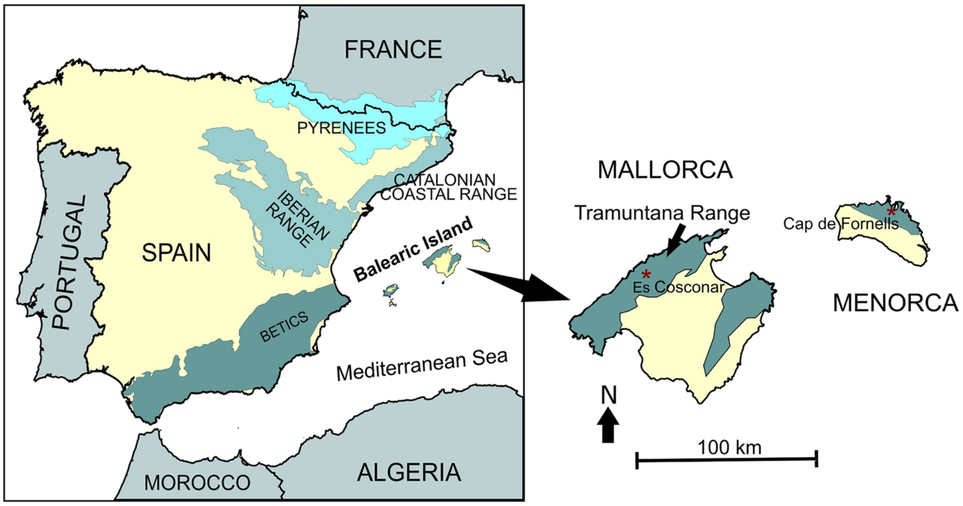


Fig. 1 Geographical and geological context of the Lower Toarcian sections of Es Cosconar and Cap de Fornells

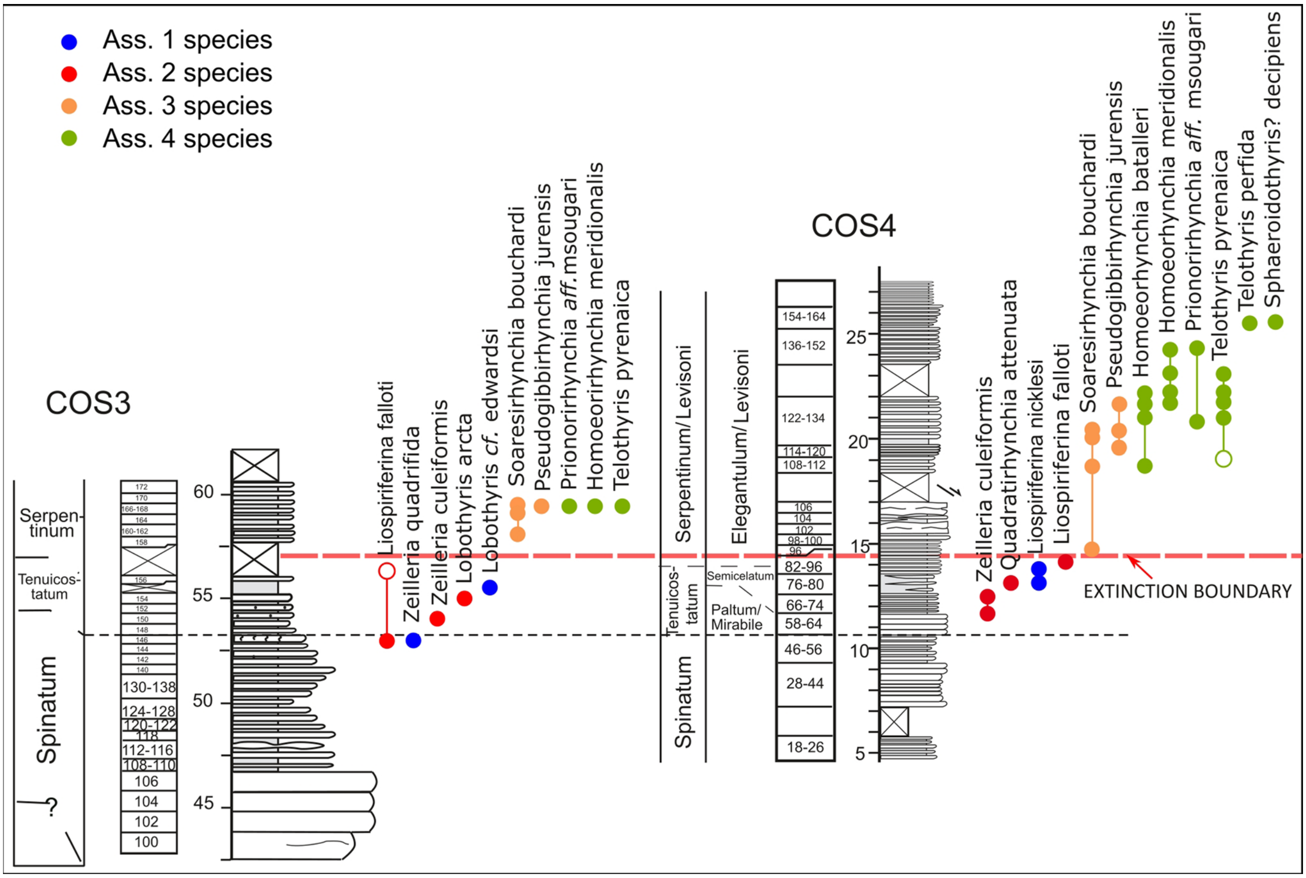


Fig. 2 Stratigraphic record of the brachiopods in the COS3 and COS4 sections. The colors of circles correspond to the assemblages identified in García Joral et al. (2011). The empty circles indicate ex situ records. Stratigraphic logs after Rosales et al. (2018)

et al., 2002; Rosales et al., 2018). The brachiopods studied in Es Cosconar come from two sections, ~ 300 m close to each other: COS3 and COS4 (Rosales et al., 2018, p. 170). Together, both sections cover the transition between two lithostratigraphic units (Fig. 2): the highest part of Es Cosconar Fm (until COS3-154 and COS4-74, and the lower part of Gorg Blau Fm (from COS3-155 and COS4-75). Both formations were described by Álvaro et al., (1984, 1989) and, in the studied section, correspond to the interval between the upper Pliensbachian (Spinatum Chronozone) and the middle Toarcian (Variabilis Chronozone). The Es Cosconar Fm is constituted in its middle part by tabular to nodular, decimetric-bedded wackestones to packstones with thin centimetric (up to 5 cm) marly interbeds. Beds on this package are rich in belemnites, brachiopods and pectinid bivalves. Above bed 106, the marl/limestone ratio increases, and the rest of the Pliensbachian succession (ca. 6.5 m) is made of an alternation of centimetric to decimetric beds of limestones and marls with brachiopods, belemnites and pectinids. Toward the upper part, the last 2 m become brownish and bioclastic, with abundant bioturbation and small silicified planispiral gastropods. The Pliensbachian-Toarcian transition is placed by Rosales et al. (2018), based on $^{87}Sr/^{86}Sr$ data, at or near a bioturbated firmground surface on bed COS3-146 (Fig. 2). This bioturbated firmground surface can be correlated between COS3 and COS4 sections. Above this surface the next 1.5 to 2 m of the succession are constituted by yellowish-tan, terrigenous-rich, silty-sandy bioclastic and bioturbated nodular limestones rich in small gastropods, along with crinoids, belemnites, pectinids and brachiopods. The top of this interval is a bioturbated, transgressive surface. The rest of the Toarcian succession (Gorg Blau Formation) is made of a hemipelagic, rhythmic alternation of marls and marly limestones rich in ammonites and brachiopods, with an overall increase in the marl/limestone ratio upward. The conservation of brachiopods is not always good and with some frequency they have been partially infilled and recrystallized, possibly because the sedimentation rate in this area was relatively high.

In COS3, the brachiopods of the Pliensbachian-Toarcian transit are studied in 8 successive levels yielding brachiopods. Above the Serpentinum Zone the sediments of the lower and middle Toarcian are partially covered, and it is not possible to carry out an accurate sampling (Fig. 2). In

COS4, brachiopods from 18 successive levels have been studied, corresponding to the chronostratigraphic interval between the upper Pliensbachian (Spinatum Zone, Hawskerense Subzone) and the Bifrons Zone (Sublevisoni Subzone) of the Toarcian.

3 Brachiopod assemblages

A total of 16 species have been identified in Es Cosconar, corresponding to 9 genera belonging to 3 orders (Spiriferinida, Rhynchonellida and Terebratulida). Their distribution is shown in Fig. 2, and some representative specimens are shown in Fig. 3. These species can be assimilated to the assemblages described for the Iberian Range by Goy et al. (1998) and García Joral and Goy (2000) slightly modified in García Joral et al. (2011)

The species recorded of the Assemblage 1 (taxa typical of the late Pliensbachian that persist at the first zone of the early Toarcian) are *Liospiriferina* aff. *nicklesi* (beds 78–92 of COS4), *Zeilleria quadrifida* (bed 146 of COS3) and *Lobothyris* cf. *edwardsi* (COS3-145). *Li.* aff. *nicklesi* (Fig. 3, 9a–c) corresponds to a relatively abundant morphology from the Pliensbachian-Toarcian transition in the Iberian Range, assimilated by Bataller (1931) to "*Spiriferina*" *nicklesi* (Corroy, 1927, p. 12, Pl. 2, Figs. 1–8) from the Sinemurian and Pliensbachian of Lorraine. This determination has been followed by Delance (1969), Goy (1974), Goy and Robles (1975) and Comas-Rengifo et al. (2006). However, the types figured by Corroy show a more circular outline and a more plicated commissure, besides being chronostratigraphically older. The Iberian form seemingly does not belong to the French species and would require a new specific name. This morphology has been also recorded in the Lusitanian Basin (Comas-Rengifo et al., 2015). *Lo. edwardsi* is a variant of

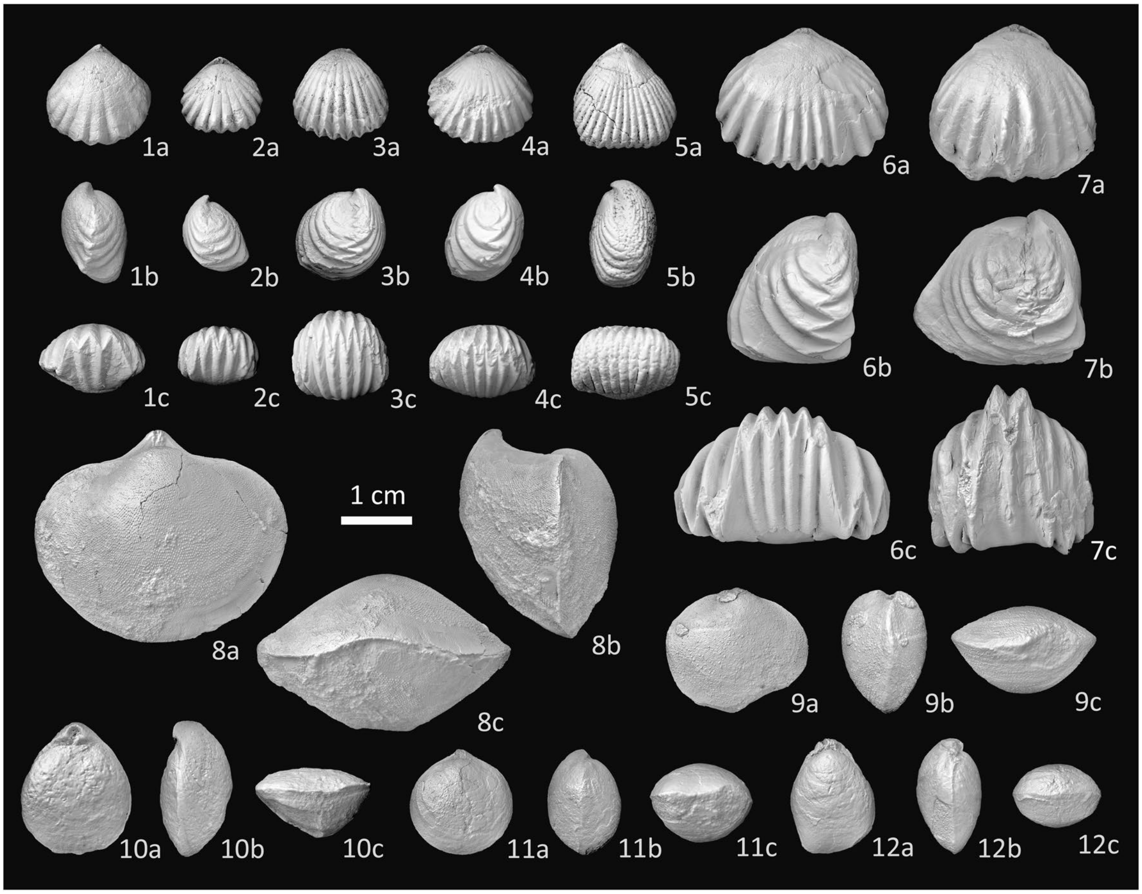


Fig. 3 Photographs of some representative specimens of the Lower Toarcian brachiopods from Es Cosconar Sect. 1: *Soaresirhynchia bouchardi* (Davidson), specimen COS3-162.1; 2: *Pseudogibbirhynchia jurensis* (Quenstedt), specimen COS4-132.1; 3–4: *Prionorhynchia* aff. *msougari* Rousselle, specimens COS3-168.2 (3) and COS3-168.1 (4); 5: *Prionorhynchia* sp, specimen COS4-126.1; 6: *Homoeorhynchia batalleri* (Dubar), specimen COS4-134.2; 7: *H. meridionalis* (Deslongchamps), specimen COS4-134.1; 8: *Liospiriferina* cf. *falloti* (Corroy); specimen COS3-157.1.; 9: *L.* aff. *nicklesi* (Corroy), specimen COS4-78.1; 10: *Lobothyris arcta* (Dubar), specimen COS3-155.1; 11: *Telothyris perfida* (Choffat), specimen COS4-112.1; 12: *Zeilleria culeiformis* Rollier, specimen COS3-150.1. In all cases, **a**: dorsal view; **b**: lateral view; **c**: frontal view. Scale bar = 1 cm

the *Lobothyris punctata* group also characteristic of the Pliensbachian-Toarcian transition of the Euro-Boreal Province (in the sense of Vörös, 2016 and Vörös & Escarguel, 2019), showing a characteristic less rounded front, usually thickened. It has been considered as a different species by Davidson (1851) and other authors, and as a variety of *Lo. punctata* (Sowerby) by Ager (1990). We prefer to distinguish it as nominal species because of its high value as chronostratigraphical marker (García Joral & Goy, 2000). The specimens assigned herein to *Z. quadrifida* correspond to the "*cornuta*" morphotype of this species, characteristic also of the Pliensbachian-Toarcian transition in the Euro-Boreal Province. This is a very typical morphology, considered by several authors as part of a continuum of variability with the "*quadrifida*" morphotype (see Delance, 1974). However, it is very rare to find both morphotypes together, since they are apparently adapted to different types of substrates: bicorne specimens are characteristic of more consistent sediments (sandy or bioclastic), while quadricorne specimens are recorded preferentially in soft, marly or clayish bottoms.

The species of the Assemblage 2 (taxa taxonomically related with those of the previous assemblage but with a more endemic distribution and almost exclusive of the Tenuicostatum Zone) are *Quadratirhynchia attenuata* (COS4-75), *Liospiriferina falloti* (COS3-147–154 and COS4-92), *Lobothyris arcta* (COS3-154) and *Zeilleria* aff. *culeiformis* (COS3-150 and COS464–74). *Q. attenuatta* is a form apparently endemic of the East-Iberian platforms system (EIPS) and the Eastern Pyrenees, distributed in the last levels of the Pliensbachian and in the Tenuicostatum Zone of the Lower Toarcian (Alméras & Fauré, 2000; Dubar, 1931; García Joral et al., 2011). Its morphology is like that of other species of *Quadratirhynchia*, but with a less square dorsal fold. *Li. falloti* is a very frequent species recorded, as the previous one, in the last levels of the Pliensbachian and in the Tenuicostatum Zone of the peri-Iberian basins: Asturian, Basque-Cantabrian, Iberian (Comas-Rengifo & Goy, 1975; Comas-Rengifo et al., 2006; García Joral & Goy, 2009; García Joral et al., 2011), the Pyrenees and the south border of Armorican Massif (Alméras & Fauré, 2000; Alméras et al., 2010), as well as northwestern Africa (Alméras et al., 2007). It is distinguished from other similar spiriferinides of the *Li. rostrata* group by a rounded outline in dorsal view and a wide posterior commissure. A similar morphology but clearly smaller (half the size) has been determined as *Li.* cf. *falloti* by Comas-Rengifo et al., (2013, 2015) in the Lusitanian Basin. In the last level below the extinction boundary in Es Cosconar (COS3-157) a specimen morphologically close to this species, but with straighter ventral umbo, has been recorded *ex-situ*. It has been provisionally determined as *Liospiriferina* cf. *falloti*. (Fig. 3, 8a-c). *Lo. arcta* (Fig. 3 10a-c) is a small and elongate form of the *Lo. punctata* group, frequently associated with the former species in the same basins. *Z.* aff. *culeiformis* (Fig. 3, 12a-c) is a small zeillerid characteristic of the lower part of the Tenuicostatum Zone from the EIPS and the Pyrenees. It includes elongated forms without indentation of the frontal commissure together with others more pentagonal and with the central part of the frontal commissure slightly retracted. The first morphotype has been named *Z.* aff. *scalprata* by Delance (1969), Goy (1974) and Alméras and Fauré (2000) and the second corresponds to *Z. culeiformis*. Like in the case of *Z. quadrifida* previously exposed, it is difficult to establish if both morphotypes correspond to different species, as stated by Alméras and Fauré (2000) or they are variants of a single species, since they appear at the same stratigraphic levels and often together. The specimens collected in Es Cosconar belong to the elongate morphotype.

The extinction boundary of the Toarcian Extinction Event (cf. Baeza-Carratalá et al., 2015, 2017; García Joral et al., 2011) is recorded in the sections studied within the interval representing the Early Toarcian Oceanic Anoxic Event (ET-OAE) as indicated by the δ^{13}C isotopic rate curves (Rosales et al., 2018), at levels COS3-157–159 and COS4-93, above the last spiriferinides and below the first *Soaresirhynchia bouchardi*. In relation with the isotopic curves (Fig. 4) its position is equivalent to that observed for the same group in other peri-Iberian basins, as in the Iberian (Danise et al., 2019; García Joral et al., 2011; Piazza et al., 2020) or the Lusitanian (Duarte et al., 2018; Suan et al., 2008). As explained above, this extinction event involved most of the marine benthic and nekto-planktic biota in a wide area, and its most plausible cause was the severe warming of sea water inferred for this time (Bailey et al., 2003; Danise et al., 2013; Fernandez López et al., 1998; Gómez & Goy, 2011; Gómez et al., 2008; McElwain et al., 2005; Rosales et al., 2004, 2018; Ruebsam et al., 2019) which extended up to the Late Bifrons Chronozone. In the case of the EIPS, which probably represented a “last refuge” for many brachiopod taxa at the beginning of the crisis (Vörös et al., 2019), the enhanced southward currents through the Laurasian Seaway related to the hyperthermal event (Arias, 2007; Bjerrum et al., 2001; Dera & Donnadieu, 2012; Ruvalcaba Baroni et al., 2018; Vörös, 2002) probably hampered northward migration of benthic organisms toward northern cooler waters, causing the extinction of those that, like many brachiopods, were unable to withstand the warming (cf. Baeza-Carratalá et al., 2015; García Joral et al., 2011). In Es Cosconar, this progressive warming episode of the Tenuicostatum Biochron is also recorded (Fig. 4), with the extinction boundary of brachiopods located at the upper part of it.

The recovery of the brachiopod fauna is recorded in Es Cosconar shortly after the extinction boundary, represented by the first occurrence of *Soaresirhynchia bouchardi* (Fig. 3, 1a-c) at the base of the Serpentinum Zone. This species is recorded from beds 94 to 124 of the COS4 section

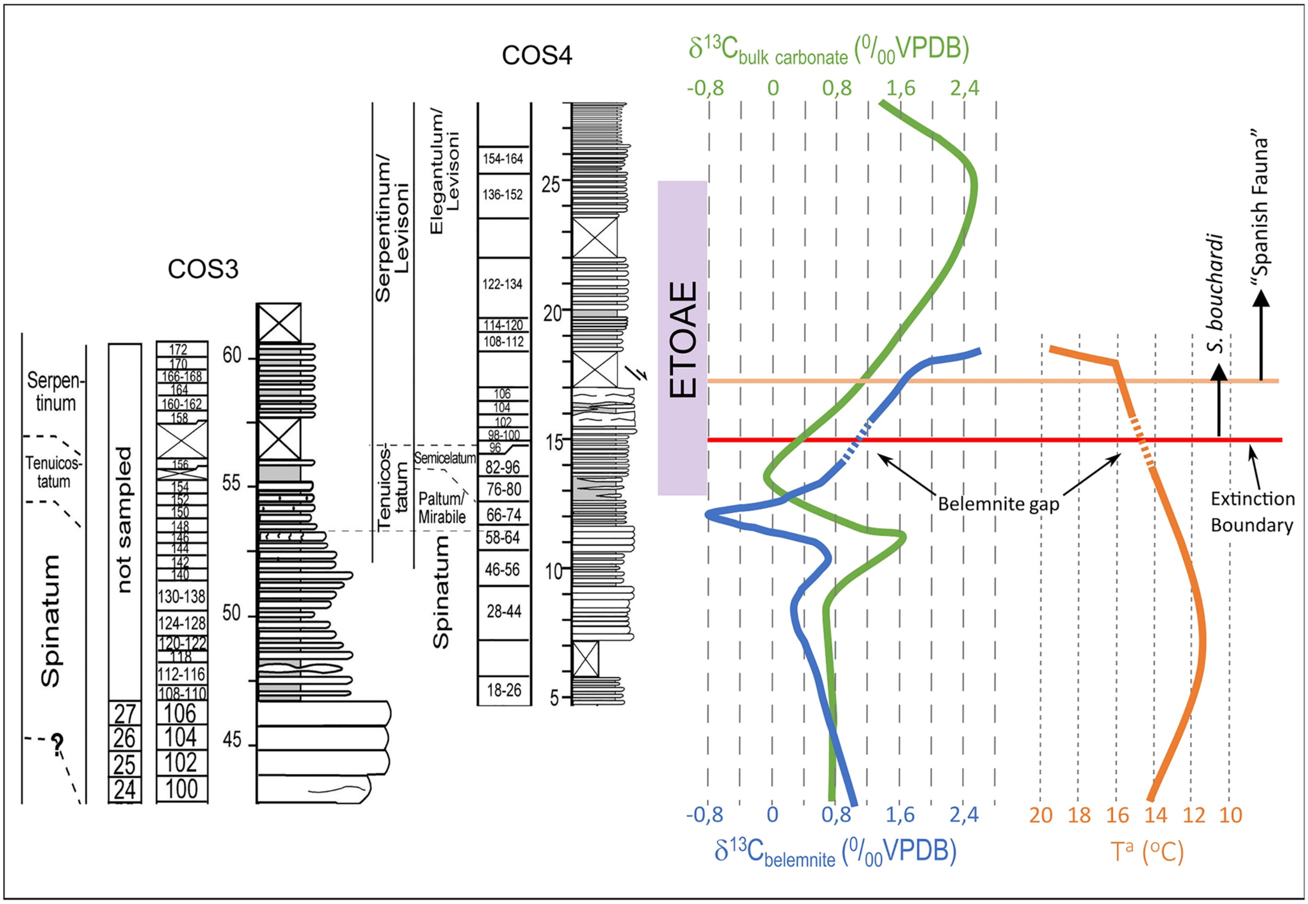


Fig. 4 Stratigraphic position of the extinction boundary and the first occurrence of the Assemblage 4 of brachiopods ("Spanish Fauna") related to the isotopic curves of δ^{13}C (of belemnites and of bulk carbonate) and the curve of seawater temperature in Es Cosconar. Stratigraphic logs and curves after Rosales et al. (2018)

and at beds 160–166 of COS3. Together with *Pseudogibbirhynchia jurensis* (Fig. 3, 2a-c), they correspond to the Assemblage 3. 1998 *So. bouchardi* is a widely distributed species, occurring from Morocco to Slovenia and Bosnia and from England to Tunisia, showing a very high variability (Ager, 1962; Alméras, 1994; Alméras & Fauré, 2000; Alméras et al., 2007, 2010; Anko, 2014; Baeza-Carratalá et al., 2011; Comas-Rengifo & Goy, 1975; Dubar, 1931; Fauré et al., 2015; Gakovic & Tchoumatchenco, 1994; Graziano et al., 2006; Rousselle, 1973). Dubar (1931) differentiated and named a number of varieties, which have been considered as different species by Alméras (1994). However, García Joral and Goy (2000) and Gahr (2002, 2005), among others, considered them a single species with opportunistic features, such as unspecialized morphology and small size, forming large populations exhibiting high polymorphism. This point of view has been followed in this work. Chronostratigraphically, it is usually recorded restricted to the Elegantulum Subzone, although Piazza et al. (2019) reported scanty records of this species in the Polymorphum Zone in Portugal. The only other species represented in this assemblage, *Ps. jurensis* (COS3-166–168, COS4-120, 124,130–32) has also a wide distribution in time and space (cf. Ager, 1962; Alméras, 1996; Alméras & Fauré, 2000; Fauré et al., 2015). It is easily distinguishable by its strong ribs, usually bifurcate and covering all the surface of the shell.

Finally, the Assemblage 4 appears in the Serpentinum Zone, at the last levels with *So. bouchardi*, and extends into the Bifrons Zone of the middle Toarcian (from bed 168 in COS3 and 110 of COS4). It is dominated by species of the genera *Homoeorhynchia*: *H. batalleri*, *H. meridionalis* and *Telothyris*: *Te. pyrenaica*, *Te. perfida*. Other species recorded from this assemblage are *Prionorhynchia* aff. *msougari*, *Pr.* sp. and *Sphaeroidothyris*? *decipiens*. *H. batalleri* and *H. meridionalis* (Fig. 3, 6–7) are part of a group of morphologies that includes many nominal species: *H. meridionalis*, *H. lusitanica*, *H. tifritensis*, *H. batalleri* and *H. pusilla*. It is likely, as suggested by Alméras (1996), that *H. batalleri* was the basal and most widely distributed form from which a set of more geographically restricted morphotypes derived. After this interpretation, the nominal separation of these morphotypes can be justified for reasons of utility, as they are not represented uniformly in space or time. In this sense, *H. meridionalis* would represent the "Iberian" form, being abundant in the Iberian Range (mainly in the Sierra de Albarracín area) and in the Catalonian Coastal Range, and very scarce or absent in other peri-Iberian basins. The case of *Telothyris* is similar. The morphology of the first described species (*Te. jauberti*) is only frequent in the central part of the Iberian Range. The type comes from Anchuela, in Guadalajara Province (Deslongchamps, 1863) whereas *Te. pyrenaica* seems to be the most frequent and widely distributed form. It is difficult to say if other nominal varieties or species, such as, *Te. jauberti leymeriei*, *Te. jauberti dubari*, *Te. nabanciensis*, *Te. monleaui*, or *Te. arnaudi* (cf. Alméras & Moulan, 1982; Alméras et al., 1996) are local variants or extreme morphologies without specific value. We have determined *Te. pyrenaica* in Es Cosconar as it corresponds to the dominant recorded morphology.

In the uppermost part of the Falciferum subzone we have recorded in COS4-154 *Telothyris perfida* (Fig. 3, 10a-c) and, at level COS4-158, the same species associated with *Sphaeroidothyris? decipiens*. Both species have been assigned to *Sphaeroidothyris* by Alméras and Moulan (1982), but this genus is characteristic of the Upper Bajocian and the Bathonian, and we do not agree with this generic determination. Despite the something similar globosity, that is found repeatedly in terebratulides, there are no raisons to relate phylogenetically species so distanced stratigraphically. *Te. perfida* has many characters in common with other species of *Telothyris*, such as the small and rounded foramen and the slight plication of the frontal commissure, therefore should belong to this genus. *Sp.? decipiens* is something different, more ovoid than globose and with bigger ovate foramen, and probably belongs to another, yet undescribed, genus.

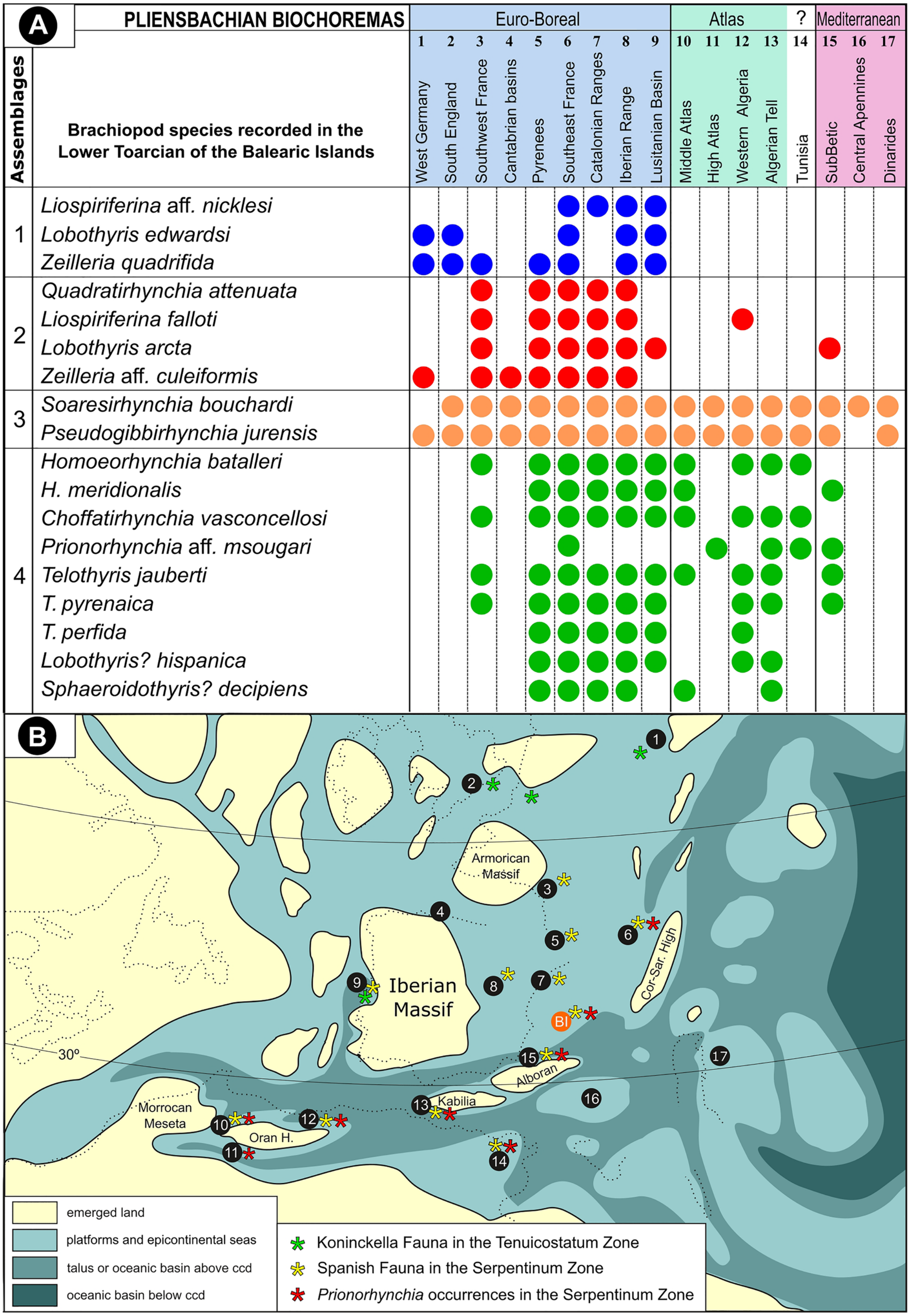
The last species identified of the Assemblage 4 is *Pr.* aff. *msougari* (COS3-168 and COS4-142), which deserves a separate comment. This species was described by Rousselle (1973) grouping together two morphologies from the Moroccan High Atlas recorded with *Hildoceras* and "Frequently with *Terebratula* cf. *vari* and *Tegulithyris*", thus corresponding to the Middle Toarcian (cf. Elmi et al., 1997). Afterwards has been cited in north Africa several times (Alméras et al., 1993, 1996, 2007; Fauré et al., 2015), in Southern France (Alméras 1996) and in the Betic Cordillera (Baeza-Carratalá et al., 2011) in similar stratigraphic position. The types were drawn, not photographed (Rousselle 1973; Fig. 1), which makes it difficult to precise its diagnostic features. In fact, there are noticeable differences in the morphology of the figured specimens attributed to this species. The form identified in Es Cosconar (Fig. 3, 3a-c, 4a-c) seems to be close to those from the Moroccan High Atlas figured by Alméras et al. (1993, pl. 2, Fig. 8), from La Verpillière (Southern France) figured by Alméras (1996, Pl. 3, Figs. 1–5), from the Ouarsensis (Algerian Tell) figured by Alméras et al., (2007, Pl. 2, Fig. 20) and from Sierra Espuña (Subbetic Zone of the Betic Cordillera) figured by Baeza-Carratalá et al., (2011, Fig. 5, 6a-c). However, it is different from other specimens from the High Atlas (Alméras et al., 1993, pl. 2, Fig. 9) and from Tunisia (Fauré et al., 2015, Fig. 7 A). The morphology recorded in Mallorca has never been identified in the Iberian and Catalonian platforms. Another specimen determined as *Prionorhynchia* sp., whose morphology reminds that of *Prionorhynchia rubrisaxensis* (sensu Rousselle 1973), has been recorded *ex-situ* in COS4-126.

The Ass. 3 and 4 are also recorded in Menorca (Llompart 1979; Appendix A) where, besides most of the species found in Mallorca, have also been recorded *Choffatirhynchia vasconcellosi* and *Lobothyris*? *hispanica*. *C. vasconcellosi* was described in the Lusitanian Basin and is frequent in the EIPS (Comas-Rengifo & Goy 1975; Dubar 1931; García Joral & Goy 2010). It has also been recorded in the Pyrenees (Alméras & Fauré, 2000) southwest France (Alméras et al., 2010) and in northwest Africa (Alméras et al., 2007; Fauré et al., 2015). Its morphology is close to many other multicostate and uniplicate rhynchonellides and has been attributed to the genus *Quadratirhynchia* by Alméras et al. (1996). However, it lacks some distinctive features of this genus (and the whole group of the tetrarhynchiids) as the recurved beak and the developed squama-glotta. On the basis of these differences, García Joral & Goy (2004) considered it as the type species of their new genus *Choffatirhynchia*. *Lo.*? *hispanica* is a large form of terebratulide, distinguishable from *Lobothyris* and *Telothyris* for its wide uniplication. As in other cases described above, this species needs a revision of its generic attribution.

4 Discussion: paleobiogeographic affinities of the early toarcian brachiopods of the balearic Islands

To establish which areas are more related from the paleobiogeographic point of view with the Balearic Islands in the Early Toarcian, a table has been build showing the presence of the Balearic species in other nearby regions (Fig. 5A). The list of Balearic species has been prepared based on the determinations established in the previous paragraphs and the update of those made by Colom (1942) and Llompart (1979).

In the Pliensbachian, a strong provincialism is observed among the Western Tethys brachiopods, which are classically separated in two main provinces, named Euro-Boreal and Mediterranean by Vörös (2016), separated by narrow



A **PLIENSBACHIAN BIOCHOREMAS**

Assemblages	Brachiopod species recorded in the Lower Toarcian of the Balearic Islands	Euro-Boreal									Atlas				?	Mediterranean		
		1 West Germany	2 South England	3 Southwest France	4 Cantabrian basins	5 Pyrenees	6 Southeast France	7 Catalonian Ranges	8 Iberian Range	9 Lusitanian Basin	10 Middle Atlas	11 High Atlas	12 Western Algeria	13 Algerian Tell	14 Tunisia	15 SubBetic	16 Central Apennines	17 Dinarides
1	*Liospiriferina* aff. *nicklesi*						●	●	●	●								
	Lobothyris edwardsi	●	●				●		●	●								
	Zeilleria quadrifida	●	●	●		●	●		●	●								
2	*Quadratirhynchia attenuata*			●		●	●	●	●									
	Liospiriferina falloti			●		●	●	●	●				●					
	Lobothyris arcta			●		●	●	●	●	●						●		
	Zeilleria aff. *culeiformis*	●		●	●	●	●	●	●									
3	*Soaresirhynchia bouchardi*		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Pseudogibbirhynchia jurensis	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●
4	*Homoeorhynchia batalleri*			●		●	●	●	●	●	●		●	●	●			
	H. meridionalis					●	●	●	●	●	●					●		
	Choffatirhynchia vasconcellosi			●		●	●	●	●	●	●		●	●	●			
	Prionorhynchia aff. *msougari*						●					●		●	●	●		
	Telothyris jauberti			●		●	●	●	●	●	●		●	●		●		
	T. pyrenaica			●		●	●	●	●	●			●	●		●		
	T. perfida					●	●	●	●	●			●					
	Lobothyris? hispanica					●	●	●	●	●			●	●				
	Sphaeroidothyris? decipiens					●	●	●	●		●			●				

◀**Fig. 5** **A** Occurrence of the brachiopod species recorded in Mallorca and Menorca and in other Western Tethys basins grouped after the Paleobiogeographic framework proposed by Vörös & Escarguel (2019) for the Pliensbachian. Occurrence data after: 1 = Quenstedt (1868–1871); Rau (1905); 2 = Davidson (1851–1878); Ager (1956–1967); 3 = Alméras et al. (2010); 4 = García Joral & Goy (2009, 2010); García Joral et al. (2011); 5 = Alméras & Fauré (2000); 6 = Alméras & Moulan (1982); Alméras (1996); Alméras & Fauré (2013); 7 = Dubar (1931); Delance (1969); Fernández López et al. (1998); 8 = García Joral & Goy (2000, 2010); 9 = Alméras et al. (1996); Comas-Rengifo et al., (2013, 2015); 10 = Elmi et al. (1991); 11 = Rousselle (1973, 1974); 12 = Elmi et al. (1985); Alméras et al. (2007); 13 = Alméras et al. (2007); 14 = Fauré et al. (2015); 15 = Baeza-Carratalá et al. (2011); Baeza-Carratalá (2011, 2013); 16 = Graziano et al. (2006); 17 = Gakovic & Tchoumatchenco (1994); Anko (2014). **B** Paleogeographic map of the Western Tethys in the Toarcian showing the location of the basins listed in **A**, modified after Bassoullet et al. (1993); paleolatitudes modified after Osete et al. (2011)

deep-sea belts that served as barriers or partial filters for brachiopod dispersal. Vörös & Escarguel (2019) added to these a third province called "Pontic" in the eastern part of the north margin of Western Tethys, and another "*Atlas biochore*" including several north African basins, intermediate between the Euro-Boreal and the Mediterranean Provinces and with a 20% of endemicity. The species of Ass.1 identified in the Balearic Islands show a clear affinity with the Pliensbachian Euro-Boreal Province. The three recognized species are present in South France, the Iberian Range and the Lusitanian Basin, whereas none of them have been recorded in the basins of the Mediterranean nor the Atlas biochoremas.

The Early Toarcian Mass Extinction had notable effects on paleobiogeography. The pliensbachian provincialism was disrupted in the Tenuicostatum Biochron in several groups, such as ammonites (Dera et al., 2011; Macchioni & Cecca 2002; Zakharov et al., 2006). The brachiopods are strongly affected by this biotic crisis in the Mediterranean Province (Baeza-Carratalá, 2013; Vörös, 2005) where they did not recover until the Aalenian-Bajocian in many areas of this biochorema. Some typical Tethyan groups show strategies to escape from their ancestral areas that were becoming unfavorable, by moving to deep refuge, as the external Subbetic (Baeza-Carratalá et al., 2017), or by migration from the intra-Tethyan to some relatively deep areas of the European Epicontinental Sea (Baeza-Carratalá et al., 2015; Vörös, 2002), where they found a suitable habitat to colonize. In these areas (Lusitanian Basin, South England, Normandy, West Germany) a characteristic association thrived, the "Koninckella Fauna" (Alméras & Elmi 1993; Alméras et al., 1989; Vörös, 2002) composed by minute species and some medium sized resilient rhynchonellides, as *Cirpa* (Baeza-Carratalá & García Joral 2020, 2022). In other shallow areas of westernmost Tethys (EIPS, Pyrenees and several South and West France basins), northwest European taxa persist, although showing renewal at the species level. These species constitute the Ass. 2, recognized also in Mallorca. Some species of this assemblage are also recorded in north Africa and the Subbetic area, whereas they are very scantily present in the areas where the Koninckella Fauna occurs (Fig. 5 B).

After the extinction of all the brachiopod species in the area of study and many others, recovery began quickly with the appearance of *Soaresirhynchia bouchardi*. This species shows opportunistic characteristics, including a very wide geographical distribution that ignores the boundaries between the Pliensbachian provinces (Fig. 5), therefore mirroring the cosmopolitalism observed in the ammonites (Dera et al., 2011). Piazza et al. (2020) have interpreted the smallest size of *So. bouchardi* relative to that of the Ass. 2, in a single locality of the Iberian Range, as due to a "reduced community shell size during the T-OAE" caused by "heat stress". However, this does not appear to apply to all areas where this species is distributed. In other areas, such as the Lusitanian Basin, the size of this species is larger than the size of the brachiopod species prior to the extinction boundary (cf. García Joral et al., 2018; Piazza et al., 2019). In our opinion, *So. bouchardi* is a pioneer species that colonized areas that had been devoid of brachiopods because of the extinction event. Ullmann et al. (2020) related the "unlikely success" of this species with a low metabolic rate which possibly allowed it to thrive in the hyperthermal event that took place at that moment.

In the last level containing *So. bouchardi,* the species of Ass. 4 appeared in Mallorca and in Menorca. This assemblage corresponds to that García Joral and Goy (1984, 2000) considered the "Spanish Bioprovince" of brachiopods, named from the so-called "Spanish Fauna" ("*Faune espagnole*" or "*Faune à facies espagnole*") of Choffat (1880), Dubar (1931) and Delance (1972), also named "Iberian" by Ager (1986) and other authors. Although "Spanish" would hold priority, perhaps a more inclusive denomination would be preferable for this biochorema, such as Ibero-Maghrebian or another that generates sufficient consensus among specialists. This assemblage is recognized in basins mainly belonging to the Atlas biochorema and to the southern part of the Euro-Boreal Province, but also including some Mediterranean areas, like the Subbetic (Fig. 5). Besides these areas, some typical elements, such as species of *Homoeorhynchia* and *Telothyris*. have been recognized in Western South America by Manceñido (1990, 2002).

In the Upper Toarcian, before the reconstruction of the earlier Euro-Boreal / Mediterranean provincialism in the Aalenian–Bajocian (cf. Vörös, 1977, 1980), two biochoremas have been recognized in the peri-Iberian basins by Andrade et al. (2016), called Ibero-Atlantic District (Lusitanian, Cantabrian, and West-Pyrenean basins) and Ibero-Mediterranean District (EIPS, Eastern Pyrenees and South France basins). The record in Mallorca of *Telothyris* cf. *depressa* (Dubar) and *Choffatirhynchia* cf. *turolensis* in the upper Bifrons or lower Variabilis Zone (Rosales et al., 2018, p. 174) indicates that the Balearic basins belong probably to the second of these districts.

Finally, the occurrence of *Prionorhynchia* aff. *msougari* in Mallorca probably indicates a closer relationship of the Balearic Islands with the southern margin than with the northern margin of the Tethys, as this species has not been recorded in Portugal nor in the EIPS. *Prionorhynchia* is one of the scarce rhynchonellide genera that survived the Early Toarcian Extinction. In the Pliensbachian it was distributed mainly in the Mediterranean Province, although reaching occasionally the European epicontinental seas. In the Late Spinatum Chronozone, *Pr. serrata* (Sowerby) has been recorded in South England (Ager 1956; Davidson 1852) and in Portugal (Comas-Rengifo et al., 2015). In the Serpentinum and Bifrons zones, *Prionorhynchia* has been recorded, besides Mallorca, in north Africa, the Subbetic and Southeast France (Fig. 5B), and has been also recorded in several of these areas in the Upper Toarcian (Alméras et al., 1996, 2007; Rousselle 1973). In the Upper Toarcian–Lower Aalenian transition, *Pr. rubrisaxensis*, a very abundant species in the Northern Calcareous Alps, has been recorded in the Iberian Range (García Joral et al., 1990; Goy et al., 1994) and possibly in South America (determined as *Sphenorhynchia*? cf. *rubrisaxensis* by Manceñido 1990), whereas it has not yet been found either in the typical west European or in the typical Mediterranean areas (García Joral 1993).

5 Conclusions

Recent sampling in the locality of Es Cosconar, in the Tramuntana Range of Mallorca (Balearic Islands), has recorded 16 species of brachiopods in the Tenuicostatum–Serpentinum chronostratigraphic interval of the Lower Toarcian, corresponding to 9 genera belonging to 3 orders (Spiriferinida, Rhynchonellida and Terebratulida).

The species of brachiopods from the Early Toarcian identified in this work and in previous ones allow recognizing, in the Balearic Islands, similar assemblages to those recorded in the East Iberian Platform System during this interval.

In the Tenuicostatum biochron, the Balearic brachiopods show high affinities with the Euro-Boreal Province, although some endemism shared whit the Iberian, Pyrenean and South French basins are observed.

After the extinction event of the early Serpentinum Biochron and the paleobiogeographic reorganization related to it, the recorded species correspond to the so-called "Spanish Province", that includes basins of the earlier (pre-extinction) Euro-Boreal, Atlas and Mediterranean biochoremas. The occurrence of *Prionorhynchia* species in this post-extinction assemblage indicates a closer affinity, within this biochorema, with the basins of the southern margin of the Tethys (north African and Betic basins) than with those located in the northern margin of the Tethys.

The paleobiogeographic evolution of the Toarcian brachiopod faunas of the Balearic Islands is consistent with their proposed paleogeographical position in the southeastern margin of Iberia, but closer to the Alboran, Kabylian and North African margins than to other peri-Iberian basins.

Apendix: Systematical update of the early Toarcian brachiopod species determined by Colom (1942) and Llompart (1979) in Mallorca and Menorca

Determinations by Colom (1942)	**This work**
Terebratula Jauberti Deslong	*Telothyris jauberti* (Deslongchamps)
T. Jauberti var. *pyrenaica* Dubar	*Telothyris pyrenaica* (Dubar)
T. Jauberti var. *Leymeriei* Dubar	*Telothyris pyrenaica* (Dubar)
T. decipiens Deslong	*Sphaeroidothyris? decipiens* (Deslongchamps)
Zeilleria cf. *subdigona* Opp	*Zeilleria* aff. *culeiformis* Rollier
Rhynchonella ranina Suess	*Gibbirhynchia* sp.
Rh. af. *curviceps* Quenst	*Gibbirhynchia* sp.
Rh. meridionalis Deslong	*Homeorhynchia meridionalis* (Deslongchamps)
Rh. af. *Linki* Choff	*Homeorhynchia* cf. *meridionalis* (Deslongchamps)
Rh. Bouchardi Dav	*Soaresirhynchia bouchardi* (Davidson)
Rh. Bouchardi var. af. *penichensis* Choff	*Soaresirhynchia bouchardi* (Davidson)
Rh. Bouchardi var. *rustica* Dubar	*Soaresirhynchia bouchardi* (Davidson)
Rh. dumbletonensis var. *attenuata* Dubar	*Quadratirhynchia attenuata* (Dubar)
Rh. batalleri Dubar	*Homeorhynchia batalleri* (Dubar)

Determinations by Colom (1942)	**This work**
Determinations by Llompart (1979)	
Stolmorhynchia bouchardi (Davidson)	*Soaresirhynchia bouchardi* (Davidson)
Homoeorhynchia batalleri (Dubar)	*Homeorhynchia batalleri* (Dubar)
H. meridionalis (Deslongchamps)	*Homeorhynchia meridionalis* (Deslongchamps)
"Rhynchonella" aff. *vasconcellosi* (Choffat)	*Choffatirhynchia vasconcellosi* (Choffat)
"Rhynchonella" sp. 1	*Choffatirhynchia vasconcellosi* (Choffat)
"R" sp. 2	*Choffatirhynchia vasconcellosi* (Choffat)
"Terebratula" jauberti Deslongchamps	*Telothyris jauberti* (Deslongchamps)
"T." jauberti var. *pyrenaica* Dubar	*Telothyris pyrenaica* (Dubar)
"T." jauberti var. *leymeriei* Dubar	*Telothyris pyrenaica* (Dubar)
"T." perfida Choffat	*Telothyris perfida* (Choffat)
"T." aff. *witnichi* Choffat	*Lobothyris? hispanica* (Dubar)
"T." sp. 1	*Lobothyris? hispanica* (Dubar)
"T." sp. 2	*Lobothyris? hispanica* (Dubar)
"T." sp. 3	*Lobothyris? hispanica* (Dubar)
"T." sp. 4	*Lobothyris? hispanica* (Dubar)

Systematic annex: name, author and year of the species cited in the text

"Rhynchonella" linki (Choffat in Dubar 1931).
"Terebratula" wittnichi Choffat 1947.
Choffatirhynchia turolensis García Joral & Goy 2004
Choffatirhynchia vasconcellosi (Choffat in Dubar 1931).
Gibbirhynchia curviceps (Quenstedt, 1856).
Homoeorhynchia batalleri (Dubar 1931).
Homoeorhynchia lusitanica (Choffat in Alméras et al., 1996).
Homoeorhynchia meridionalis (Deslongchamps 1863).
Homoeorhynchia pusilla García Joral & Goy 2010
Homoeorhynchia tifritensis (Flamand, 1911).
Liospiriferina falloti (Corroy 1927).
Liospiriferina nicklesi (Corroy 1927).
Lobothyris arcta (Dubar 1931).
Lobothyris edwardsi (Davidson 1851).
Lobothyris punctata (Sowerby, 1813).
Lobothyris? *hispanica* (Dubar 1931).
Prionorhynchia rubrisaxensis (Rothpletz, 1886).
Prionorhynchia msougari Rousselle 1973
Prionorhynchia serrata (Sowerby, 1825).
Pseudogibbirhynchia jurensis (Quenstedt, 1858).
Quadratyrhynchia attenuata (Dubar 1931).
Soaresirhynchia bouchardi (Davidson 1852).
Soaresirhynchia rustica (Dubar 1931).
Soaresirhynchia penichensis (Choffat in Dubar 1931).
Sphaeroidothyris? *decipiens* (Deslongchamps 1863).
Sphaeroidothyris? *vari* (Rollier, 1918).
Telothyris arnaudi Alméras & Moulan 1982
Telothyris depressa (Dubar 1931).
Telothyris jauberti (Deslongchamps 1863).
Telothyris leymeriei (Dubar 1931).
Telothyris monleaui Alméras & Moulan 1982
Telothyris nabanciensis (Choffat, 1947).
Telothyris perfida (Choffat, 1947).
Telothyris pyrenaica (Dubar 1931).
Tetrarhynchia ranina (Suess, 1860).
Zeilleria culeiformis Rollier, 1919.
Zeilleria quadrifida (Lamarck, 1819).
Zeilleria scalprata (Quenstedt, 1858).
Zeilleria subdigona (Oppel, 1853).

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