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 Kabylia 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 Catalan 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,
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.” 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...
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 ⁸⁷Sr/⁸⁶Sr 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).
COS4, brachiopods from 18 successive levels have been studied, corresponding to the chronostratigraphic interval between the upper Pliensbachian (Spinatum Zone, Hawksker-ense 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 L. 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.

Fig. 3 Photographs of some representative specimens of the Lower Toarcian brachiopods from Es Cosconar Sect. 1: Soaressrhyncha bouchardi (Davidson), specimen COS3-162.1: 2: Pseudogibbirohynchia jurensis (Quenstedt), specimen COS4-132.1: 3–4: Prionorhynchia aff. msougi 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.
the Lobothyris punctata group also characteristic of the Pleniscbachian-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 (1900). We prefer to distinguish it as a 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 Pleniscbachian-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: biconcave 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. attenuata is a form apparently endemic of the East-Iberian platforms system (EIPS) and the Eastern Pyrenees, distributed in the last levels of the Pleniscbachian 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 Pleniscbachian 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 southern 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 δ13C 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 nektobenthic 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 Laurussian 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.
and at beds 160–166 of COS3. Together with *Pseudogibb unhynchia jurensis* (Fig. 3, 2a-c), they correspond to the Assemblage 3. *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 Polymorphism 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 bifurcated 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 *Pronorhynchia 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 Catalonia 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 Anchemuella, 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 similar globosity, that is found repeatedly in terebratulides, there are no reasons 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. 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 Ouatorsens (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 Catalan 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 rhychonellides 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. Plenbsbachian Biochoremas

| Assemblages                                                                 | Euro-Boreal               | Atlas       | ? | Mediterranean |
|-----------------------------------------------------------------------------|---------------------------|-------------|---|---------------|
| **Brachiopod species recorded in the Lower Toarcian of the Balearic Islands** |                           |             |   |               |
| 1. Liospiniferina aff. nicklesi                                             | West Germany              |             |   |               |
| Zeilleria quadrifida                                                        | South England             |             |   |               |
| Lobothyris edwardsi                                                         | Southwest France          |             |   |               |
| Quadratirhynchia attenuata                                                  | Cantabrian basins         |             |   |               |
| 2. Liospinferina falloti                                                    | Pyrenees                  |             |   |               |
| Lobothyris arcta                                                            | Southeast France          |             |   |               |
| Zeilleria aff. culeiformis                                                  | Catalanian Ranges         |             |   |               |
| 3. Soaresirhynchia bouchardi                                                | Iberian Ranges            |             |   |               |
| Pseudogibbirhynchia jurensis                                                | Lyuliyan Basin            |             |   |               |
| 4. Homoeorhynchia batalleri                                                | Middle Atlas              |             |   |               |
| H. meridionalis                                                             | High Atlas                |             |   |               |
| Choffatirhynchia vasconcellosi                                             | Western Algeria            |             |   |               |
| Prionorhynchia aff. msougarri                                              | Algerian Tell             |             |   |               |
| 5. Telothyris jauberti                                                      | Tunisia                   |             |   |               |
| T. pyrenaica                                                                | Subbetic                   |             |   |               |
| 6. T. perfida                                                               | Central Apennines         |             |   |               |
| Lobothyris? hispanica                                                      | Dinarides                 |             |   |               |
| Sphaeroidothrys? decipiens                                                 |                           |             |   |               |

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**B. Map**

- Aran Massif
- Iberian Massif
- Moroccan Meseta
- Orian H.
- Kabila
- Alboran
- Koninckella Fauna in the Tenuicostatum Zone
- Spanish Fauna in the Serpentium Zone
- Prionorhynchia occurrences in the Serpentium Zone

**Legend**

- Emerged land
- Platforms and epicontinental seas
- Talus or oceanic basin above ccd
- Oceanic basin below ccd
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, 2003; Vörös, 2005) where they did not recover until the Aalenian-Bajocian in many areas of this biochorema. Some typical Tethyan species 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 rhychonellides, 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 cosmopolitism 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 Teolythis, 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 (Rosas 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 rhyynchonellide 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 with 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.

### Appendix: 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. *caleiformis* Rollier |
| *Rhychnonella 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. penichenis* Choff | *Soaresirhynchia bouchardi* (Davidson) |
| *Rh. Bouchardi* var. *rustica* Dubar | *Soaresirhynchia bouchardi* (Davidson) |
| *Rh. dumbletomensis* var. *attenuata* Dubar | *Quadratirhynchia attenuata* (Dubar) |
| *Rh. batalleri* Dubar | *Homeorhynchia batalleri* (Dubar) |
Systematic annex: name, author and year of the species cited in the text

“Rhychonella” linki (Choffat in Dubar 1931).
“Terebratula” wittnichi Choffat 1947.
Choffatirhynchia turoensis García Joral & Goy 2004
Choffatirhynchia vasconcellosi (Choffat in Dubar 1931).
Gibbirhynchia curvipes (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 trifritenis (Flamand, 1911).
Liospiriferina falloti (Corroy 1927).
Liospiriferina nickeri (Corroy 1927).
Lobothyris arcta (Dubar 1931).
Lobothyris edwardsi (Davidson 1851).
Lobothyris punctata (Sowerby, 1813).
Lobothyris? hispanica (Dubar 1931).
Prionorhynchia rubrisaxensis (Rothpletz, 1886).
Prionorhynchia mosagari 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 montealei 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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References

Ager, D.V. (1956). A monograph of the British Liassic Rhynchonellidae. Part i. The Palaeontographical Society London, 110, 1–50.

Ager, D.V. (1958). A monograph of the British Liassic Rhynchonellidae. Part ii. The Palaeontographical Society London, 112, 51–84.

Ager, D.V. (1962). A monograph of the British Liassic Rhynchonellidae. Part iii. The Palaeontographical Society London, 116, 85–136.

Ager, D.V. (1967). A monograph of the British Liassic Rhynchonellidae. Part iv. The Palaeontographical Society London, 121, 137–172.

Ager, D.V. (1971). Space and time in brachiopod history. In F. A. Midddemiss, P. F. Rawson, & G. Newall (Eds.), Faunal Provinces in Space & Time, Geological Journal Special Issue 4 (pp. 95–110). Seel House Press.

Ager, D.V. (1973). Mesozoic Brachiopoda. In A. Hallam (Ed.), Atlas of Palaeoecography (pp. 431–436). Amsterdam: Elsevier.

Ager, D.V. (1986). Migrating fossils, moving plates and expanding Earth. Modern Geologist, 10, 377–390.

Ager, D.V. (1990). British Liassic Terebratulida (Brachiopoda). Monograph of the Palaeontological Society London, 582, 1–39.

Alméras, Y., Elmi, S., Mouterde, R., Ruget, C., & Rocha, R. (1989). Atlas des Rhynchonellidae de la bordure sud du Massif Armoricain (Vendée, Deux-Sèvres, France): Paléontologie et chronostatigraphie. Bulletin de la Société des Sciences naturelles de l’Ouest de la France, Nantes, h.s. 1010–1, 1–131.

Alméras, Y. (1994). Le genre Soaresirhynchia nov. (Brachiopoda, Rhynchonellidae) dans le Toarcien du sous-bassin du bassin Nord-lusitanien (Portugal). Documents Des Laboratoires De Géologie De Lyon, 138, 1–123.

Alméras, Y., Elmi, S., & Fauré, Ph. (2007). Les brachiopodes liasiques d’Algérie occidentale. Documents Des Laboratoires De Géologie De Lyon, 162, 1–241.

Alméras, Y., & Elmi, S. (2000). Les Brachiopodes liasiques des Pyrénées. Paléontologie, Biostratigraphie, Paléobiogéographie Et Paléoenvironnements. Strata, 36, 1–395.

Alméras, Y., & Fauré, Ph. (2015). Evolution Paléogéographique du Toarcien et influence sur les peuplements. In: Rocha, R.B., Soares, A.F. (Eds.), International Symposium on Jurassic Stratigraphy, Lisboa. 1988, pp. 687–698.

Alméras, Y., Bécaud, M., & Cougnon, M. (2010). Brachiopodes liasiques de la Bordure sud du Massif Armoricain (Vendée, Deux-Sèvres, France): Paléontologie et chronostatigraphie. Bulletin de la Société des Sciences naturelles de l’Ouest de la France, Nantes, h.s. 1010–1, 1–135.

Alméras, Y. (1994). Le genre Soaresirhynchia nov. (Brachiopoda, Rhynchonellacea, Wellerellidae) dans le Toarcien du sous-bassin du bassin Nord-lusitanien (Portugal). Documents Des Laboratoires De Géologie De Lyon, 130, 1–135.

Alméras, Y. (1996). Les Brachiopodes toariens et aaleniens inférieurs du Bassin du Rhône. Paléontologie et biostratigraphie. Révision de la collection DUMORTIER et compléments. Documents Des Laboratoires De Géologie De Lyon, 138, 1–123.

Alméras, Y., Ameur, M., & Elmi, S. (1993). Prionorhynchia regia (ROTHPLETZ), Rhynchonellidé du Liais maghrebien et évolution du genre Prionorhynchia BUCKMAN. Bolletino Della Società Palaeontologica Italiana., 32, 59–77.

Alméras, Y., & Elmi, S. (1993). Palaeogeography, physiography, palaeoenvironments and brachiopod communities. Example of the Liassic brachiopods in the Western Tethys. Palaeogeography, Palaeoclimatology, Palaeoecology, 100, 95–108. https://doi.org/10.1016/0031-0182(93)90035-H

Alméras, Y., Elmi, S., & Fauré, Ph. (2007). Les Brachiopodes liasiques d’Algérie occidentale. Documents Des Laboratoires De Géologie De Lyon, 138, 1–123.

Alméras, Y., & Elmi, S. (1993). Prionorhynchia regia (ROTHPLETZ), Rhynchonellidé du Liais maghrebien et évolution du genre Prionorhynchia BUCKMAN. Bulletin de la Société Paléontologique Italienne., 32, 59–77.

Alméras, Y., & Elmi, S. (1993). Palaeogeography, physiography, palaeoenvironments and brachiopod communities. Example of the Liassic brachiopods in the Western Tethys. Palaeogeography, Palaeoclimatology, Palaeoecology, 100, 95–108. https://doi.org/10.1016/0031-0182(93)90035-H
Baeza-Carratalá, J. F., & Sepehriannasab, B. (2014). Early Jurassic brachiopods from the northeastern margin of the Western Tethys (Central Iran) and their paleobiogeographical significance. *Geobios, 47*, 3–17. https://doi.org/10.1016/j.geobios.2013.12.002

Bailey, T. R., Rosenthal, Y., McArthur, J. M., van de Schootbrugge, B., & Thrillwall, M. F. (2003). Paleoceanographic changes of the late Pliensbachian–early Toarcian interval: A possible link to the genesis of an oceanic anoxic event. *Earth and Planetary Science Letters, 212*, 307–320. https://doi.org/10.1016/S0012-821X(03)00278-4

Bassoullet, J.P., Elmi, S., Poisson, A., Ricou, L.E., Cecca, F., Beltrán, A., & Vrielynck, B. (eds.). *Atlas Tethys Paleoenvironmental Maps, Rueil-Malmaison, Beicip-Franlab.*

Bataller, J. R. (1931). Las “*Spiriferina*” de las colecciones paleontológicas del Instituto Geológico y Minero de España. *Boletín Del Instituto Geológico y Minero De España, 52*, 227–250.

Bjerrum, C. J., Surlyk, F., Callomon, J. H., & Slingerland, R. L. (2001). Jurassic (latest Toarcian) brachiopods from the northeastern margin of the Palaeomargin (Western Tethys) and its significance. *Geobiology, 3*, 183–200. https://doi.org/10.1016/j.geobiology.2009.12.002

Bourrouilh, R. (2016). The Balearic Islands in the Alpine Orogeny. *Boletín Geológico y Minero, 127*(2/3), 527–546.

Butlletí De La Institució Catalana De Història Natural, 101, 147–157.

Comas-Rengifo, M. J., García Joral, F., Goy, A., Reolid, M., Rita, P., Félix, F., & Rocha, R. B. (2015). Latest Pliensbachian – early Toarcian brachiopod assemblages from the Peniche section (Portugal) and their correlation. *Episodes, 38*, 2–8. https://doi.org/10.18814/episodes/2015/38/1001

Comas-Rengifo, M. J., García Joral, F., & Goy, A. (2006). Spiriferinida (Brachiopoda) del Jurásico Inferior del NE y N de España: Distribución y extinción durante el evento anóxico oceánico del Toarcien Inferior. *Boletín Real Sociedad Española De Historia Natural (geol)*, 101, 147–157.

Danise, S., Twitchett, R. J., & Little, C. T. S. (2015). Environmental controls on Jurassic marine ecosystems during global warming. *Geology, 43*, 263–266. https://doi.org/10.1130/G36390.1

Danise, S., Twitchett, R. J., Little, C. T. S., & Clémence, M.-E. (2013). The impact of global warming and anoxia on marine benthic community dynamics: an example from the Toarcian (Early Jurassic). *PLoS ONE, 8*(2), e56255. https://doi.org/10.1371/journal.pone.0056255

Dera, G., & Donnadieu, Y. (2012). Modeling evidences for global warming, Arctic seawater freshening, and sluggish oceanic circulation during the Early Toarcian anoxic event. *Paleogeography, Paleoclimatology, Paleoecology, 386*, 104–118. https://doi.org/10.1016/j.palaeo.2013.05.010

Delance, J. H. (1972). Problèmes posés par la variation géographique des espèces, leurs implications stratigraphiques. Exemples pris chez les brachiopodes jurassiques. *Mémoires du B.R.G.M.*, 77, 69–76.

Delance, J. H. (1974). Zeillerides du Lias d’Europe occidental. Systematique des populations, phylogénie, biostratigraphie. *Mémoire Géologique de l’Université de Dijon 2, 408 p.*

Dera, G., Neige, P., Demmergues, J.-L., & Brayard, A. (2011). Ammonite paleobiogeography during the Pliensbachian-Toarcian crisis (Early Jurassic) reflecting palaeoclimate, eustasy, and extinctions. *Global and Planetary Change, 78*, 92–105. https://doi.org/10.1016/j.gloplacamb.2011.05.009

Dera, G., Neige, P., Demmergues, J.-L., Fara, E., Laffont, R., & Pellenard, P. (2010). High resolution dynamics of Early Jurassic marine extinctions: the case of Pliensbachian-Toarcian ammonites (Cephalopoda). *Journal of the Geological Society, London, 167*, 21–33. https://doi.org/10.1144/0016-7492009-068

Dubost, G. (1986). Études critiques sur des Brachiopodes nouveaux ou peu connus. *Art. 7: Brachiopodes recueillis par M. De Verneuil dans le Lias d’Espagne. Bulletin De La Société Linnéenne De Normandie, 3*, 64–76.

Duarte, L. V., Comas-Rengifo, M. J., Hesselbo, S., Mattioli, E., Suan, G. (coordinators), Baker, S., Cabral, M. C., Correia, V., García Joral, F., Goy, A., Reolid, M., Rita, P., Félix, F., Paredes, R., Pittet, B., & Rocha, R. B. (2018). The Toarcian Oceanic Anoxic Event at Peniche. An exercise in integrated stratigraphy - Stop 1.3. In: Duarte, L.V., & Silva, R.L. (eds.), *2nd International Workshop on the Toarcian Oceanic Anoxic Event: Field Trip Guidebook*, 33–54.

Dubar, G. (1931). Brachiopodes liasiques de Catalogne et des régions voisines. *Butlletí De La Institució Catalana De Historia Natural, 31*, 103–180.

Elmi S., Almeras Y., & Benshili K. (1991). Influence of the evolution paléogéographique sur les peuplements au cours du Lias dans le Moyen-Atlas marocain. *Sciences Géologiques, Bulletins et mémoires., Strasbourg, 83* (1989), 115–131.
Elmi, S., Gabilly, J., & Mouterde, R., (1997). Toarcien. In: Hantzpergue, P., & Cariou, E. (Eds.), Biostratigraphie du Jurassique ouest européen et méditerranéen. Bulletin Centre Recherche Elf Expl-Prod., 17, 25–36.

Elmi, S., Almeras, Y., Ameur, M., & Benhamou, M. (1985). Précisions biostratigraphiques et paléoécologiques sur le Lias des environs de Tiffrit (Saïda, Algérie occidentale). Cahiers De L'Institut Catholique De Lyon, 14, 15–42.

Fallot, P. (1922). Étude Géologique de la Sierra de Majorque. Librairie Polytechnique Ch. Bérançon, Paris, 481 p.

Fallot, P. (1932). Essais sur la répartition des terrains secundaires et Tertiaries dans le domaine des Alpides espagnoles: Géologie du Méditerranée Occidental, II: Le Lias, 29–64.

Fallot, P. (1914). Sur la tectonique de la Sierra de Majorque. Compte Rendu De L’ Académie Des Sciences, Paris, 158, 645.

Fauré, P., Alméras, Y., Sekatni, N., Arfaoui, M.S., & Zargouni, F. (2015). Les Brachiopodes du Jurassique inférieur et moyen en Tunisie centrale ( Axe Nord-Sud). Un nouveau témoin du Domaine paléobiogéographique ouest-téthysien. Geodiversitas, 37 (1), 31–57. doi:https://doi.org/10.5252/g2015n1a2

Fernandez, A., Korte, C., Ullmann, C. V., Looser, N., Wohlwend, S., & Bernasconi, S. M. (2021). Reconstructing the magnitude of Early Toarcian (Jurassic) warming using the reordered clumped isotope compositions of belemnites. Geochimica Et Cosmochimica Acta, 293, 308–327. https://doi.org/10.1016/j.gca.2020.10.005

Fernández-López, S., García Joral, F., Gómez, J. J., Henriches, M. H., & Martínez, G. (1998). La diferenciación paleogeográfica de la Cuenca Catalana al principio del Jurásico Medio. Revista Española de Paleontología, 1(1)–2, 3–22.

Fourcade, E., Azéma, J., Chabrier, G., Chauve, P., Foucault, A., & Rangeard, Y. (1977). Liaisons paléogéographiques au mésozoico entre les zones externes bétiennes, corso sardes et alpines. Revue de Géographie physique et Géologie dynamique (s.2) 19, 377–388.

Gahr, M. E. (2002). Palïología des Makrobiens aus dem Untertoirac/SW-Europas. Beringeria, 31, 3–204.

Gahr, M. E. (2005). Response of lower Toarcian (Lower Jurassic) macrrobenthos of the Iberian Peninsula to sea-level changes and mass extinction. Journal of Iberian Geology, 31, 197–215.

Gakovic, M., & Tchouatchenko, V. P. (1994). Jurassic Brachiopods from the Dinarides (N-E Herzegovina). Geologica Balkanica, Sofia, 24(3), 13–29.

García Joral, F. (1993). The Aalenian Rhynchonellids from the North Iberian Range, Spain), a possible Stratotype for the baseof the Aalenian Stage. Miscelanea Servizio Geologico Nazionale, 5, 1–31.

Graziano, R., Buono, G., & Taddei Ruggiero, E. (2006). Lower Toarcian (Jurassic) brachiopod-rich carbonate facies of the Gran Sasso range (central Apennines, Italy). Bollettino Della Società Paleontologica Italiana, 45, 61–74.

Guerrera, F., Martin Algarrà, A., & Perrone, V. (1993). Late oligocene-miocene syn/late- orogenic successions in Western and Central Mediterranean chains from the Betic Cordillera to the Southern Apennines. Terra Nova, 5(6), 525–544. https://doi.org/10.1111/j.1365-3121.1993.tb00302.x

García Joral, F., & Goy, A. (2000). Stratigraphic distribution of Toarcian brachiopods from the Iberian Range (Spain) and its relation to Depositional Sequences. GeoResearch Forum, 6, 381–386.

García Joral, F., & Goy, A. (2004). Caracterización de Choffia/Choffithyris nov. gen. (Brachiopoda, Rhynchonellida) en el Toarciano (Jurásico) de la Cordillera Ibérica (España). Boletín De La Real Sociedad Española De Historia Natural (geología), 99, 237–250.

García Joral, F., & Goy, A. (2009). The Toarcian (Lower Jurassic) brachiopods from Asturias (N Spain): stratigraphic distribution, critical events and palaeobiogeography. Geobios, 42, 255–264. https://doi.org/10.1016/j.geobios.2008.10.007

García Joral, F., Goy, A., & Ureta, M. S. (1990). Las sucesiones de brachiópodos en el tránsito Lías/Dogger en la Cordillera Ibérica. Cuadernos De Geologia Ibérica, 14, 55–65.

Gómez, J. J., & Goy, A. (2011). Warming-driven mass extinction in the early Toarcian (Early Jurassic) of northern and central Spain. Correlation with other time-equivalent European sections. Palaeogeography, Palaeoclimatology, Palaeoecology, 306, 176–195. https://doi.org/10.1016/j.palaeo.2011.04.018

Gómez, J. J., Goy, A., & Canales, M. L. (2008). Seawater temperature and carbon isotope variations in belemnites linked to mass extinction during the Toarcian (Early Jurassic) in Central and Northern Spain. Comparison with other European sections. Palaeogeography, Palaeoclimatology, Palaeoecology, 258, 28–58. https://doi.org/10.1016/j.palaeo.2007.11.005

Goy, A. (1974): El Lias de la mitad norte de la Rama Castellana de la Cordillera Ibérica. Thesis Universidad Complutense de Madrid (unpublished), 940 pp.

Goy, A., & Robles, F. (1975): Resultado de un estudio sobre braquio-podos liáicos del NE de Guadalajara. Boletín de la Real Sociedad Española de Historia Natural (vol. extraord., 1971) 1, 243–255.

Goy, A., Comas-Rengifo, M. J., Arias, C., García Joral, F., Gómez, J. J., Herrero, C., Martínez, G., & Rodrigo, A. (1998). El Tránsito Pliensbachiense/Toarcienne en el Sector Central de la Rama Aragonesa de la Cordillera Ibérica (España). Cahiers De L'université Catholique De Lyon, 10, 159–179.

Goy, A., Ureta, S., Arias, C., Canales, M. L., García Joral, F., Herrero, C., Martínez, G., & Perilli, N. (1994). The Fuentelsaz section (Iberian Range, Spain), a possible Stratotype for the base of the Aalenian Stage. Miscelanea Servizio Geologico Nazionale, 5, 1–31.

Guerrera, F., Martin Algarrà, A., & Perrone, V. (1993). Late oligocene-miocene syn/late- orogenic successions in Western and Central Mediterranean chains from the Betic Cordillera to the Southern Apennines. Terra Nova, 5(6), 525–544. https://doi.org/10.1111/j.1365-3121.1993.tb00302.x

Hallam, A. (1986). The Pliensbachian and Tithonian extinction events. Nature, 319, 765–768.

Hallam, A. (1987). Radiations and extinctions in relation to environmental change in the marine Jurassic of Northwest Europe. Palaeobiology, 13, 152–168.

Harries, P. J., & Little, C. T. S. (1999). The early Toarcian (Early Jurassic) and the Cenomanian-Turonian (Late Cretaceous) mass extinctions: Similarities and contrasts. Palaeogeography, Palaeoclimatology, Palaeoecology, 154, 39–66. https://doi.org/10.1016/S0031-0182(99)00086-3

Little, C. T. S., & Benton, M. J. (1995). Early Jurassic mass extinction: A global long-term event. Geology, 23, 495–498. https://doi.org/10.1130/0091-7613(1995)023%3c0495:EMEAG%3e2.3.CO;2

Llompart, C. (1979). Aportaciones a la Paleontología del Lias de Menorca. Boletín De La Sociedad De Historia Natural De Baleares, 23, 87–116.

García Joral, F., & Goy, A. (1984). Características de la fauna de braquiópodos del Toarciano Superior en el Sector Central de la Cordillera Ibérica (Noreste de España). Estudios Geológicos, 40, 55–60.
Vörös, A. (2005). The smooth brachiopods of the Mediterranean Jurassic: Refugees or invaders? *Palaeogeography, Palaeoclimatology, Palaeoecology*, 223, 222–242. https://doi.org/10.1016/j.palaeo.2005.04.006

Vörös, A. (2016). Early Jurassic (Pliensbachian) brachiopod biogeography in the western Tethys: The Euro-Boreal and Mediterranean faunal provinces revised. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 457, 170–185. https://doi.org/10.1016/j.palaeo.2016.06.016

Vörös, A., & Escarguel, G. (2019). Brachiopod palaeobiogeography in the western Tethys during the Early Jurassic diversity maximum: introduction of a Pontic Province. *Lethaia*, 53, 72–90. https://doi.org/10.1111/let.12337

Vörös, A., Kocsis, Á. T., & Pálfy, J. (2019). Mass extinctions and clade extinctions in the history of brachiopods: Brief review and a post-Paleozoic case study. *Rivista Italiana Di Paleontologia e Stratigrafia*, 125(3), 649–662. https://doi.org/10.13130/2039-4942/12184

Wignall, P. B., Newton, R. J., & Little, C. T. (2005). The timing of paleoenvironmental change and cause-and-effect relationships during the Early Jurassic mass extinction in Europe. *American Journal of Science*, 305(10), 1014–1032. https://doi.org/10.2475/ajs.305.10.1014

Zakharov, V. A., Shurygin, B. N., Il’ina, V. I., & Nikitenko, B. L. (2006). Pliensbachian-Toarcian biotic turnover in North Siberia and the Arctic Region. *Stratigraphy and Geological Correlation*, 14, 399–417. https://doi.org/10.1134/S0869593806040046