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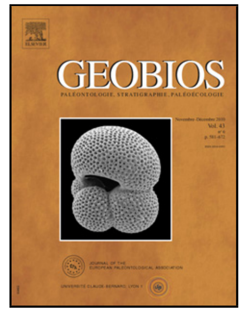

Title: Ammonite-benthic Foraminifera turnovers across the Lower-Middle Jurassic transition in the Lusitanian Basin (Portugal)

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Abstract: This paper describes and characterises the co-occurrence of ammonite and benthic foraminiferal assemblages across the São Gião outcrop (Central Portugal), a reference section for the Lower-Middle Jurassic boundary of the Lusitanian Basin. The upper Toarcian-lower Aalenian marls and marly-limestones in this section provide a precise and detailed ammonite-based biostratigraphic zonation, with a mixed assemblage of northwest European and Mediterranean faunal elements, associated with benthic foraminifera assemblages with northern hemisphere affinities, both correlatable with the Aalenian GSSP at the Fuentelsaz section (Iberian Cordillera, Spain). A total of 447 well-preserved ammonite specimens and 13.116 foraminifera have been studied and no evidence was detected of any taphonomic processes that could have changed the original assemblages.
From a biostratigraphic point of view, the ammonite record has enabled 4 biostratigraphic units to be recognised (the Mactra and Aalensis subzones of the Aalensis Biozone in the upper Toarcian, and Opalinum and Comptum subzones of the Opalinum Biozone in the lower Aalenian). With regard to the benthic foraminifera, the taxa identified have enabled the Astacolus dorbignyi Zone and 11 bioevents to be identified, most of which representing local biostratigraphic proxies. However, the increase in the relative abundance of Lenticulina exgaleata Dieni from the upper part of the Opalinum Subzone to the lower part of the Comptum Subzone indicates regional value. The constant and continuous ammonite record of northwest European taxa, together with typical Mediterranean taxa - namely Grammoceratinae - throughout the section, the high relative abundance of representatives of Miliolina - generally interpreted as foraminifers typical of shallow waters -, and the absence of foraminiferal forms typical of cool waters, do not support the inference of cool seawaters temperatures attributed to the Early Aalenian, or the global character of the "Comptum cooling event", at least with reference to the Lusitanian Basin.

Ammonite-benthic Foraminifera turnovers across the Lower-Middle Jurassic transition in the Lusitanian Basin (Portugal)[✡]

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Abstract

This paper describes and characterises the co-occurrence of ammonite and benthic foraminiferal assemblages across the São Gião outcrop (Central Portugal), a reference section for the Lower-Middle Jurassic boundary in the Lusitanian Basin. The upper Toarcian-lower Aalenian marls and marly-limestones in this section provide a precise and detailed ammonite-based biostratigraphic zonation, with a mixed assemblage of northwest European and Mediterranean faunal elements, associated with benthic foraminifera assemblages with northern hemisphere affinities, both correlatable with the Aalenian GSSP at the Fuentelsaz section (Iberian Cordillera, Spain). A total of 447 well-preserved ammonite specimens and 13.116 foraminifera have been studied; no evidence was detected of any taphonomic processes that could have changed the original assemblages. From a biostratigraphic point of view, the ammonite record has enabled 4 biostratigraphic units to be recognised (the Mactra and Aalensis subzones of the Aalensis Biozone in the upper Toarcian, and the Opalinum and Comptum subzones of the Opalinum Biozone in the lower Aalenian). With regard to the benthic foraminifera, the taxa identified have enabled the *Astacolus dorbignyi* Zone and 11 bioevents to be identified, most of which representing local biostratigraphic proxies. However, the increase in the relative abundance of *Lenticulina exgaleata* Dieni from the

upper part of the Opalinum Subzone to the lower part of the Comptum Subzone has a regional value. The constant and continuous ammonite record of northwest European taxa, together with typical Mediterranean taxa – namely Grammoceratinae – throughout the section, the high relative abundance of Miliolina representatives – generally interpreted as foraminifers typical of shallow waters –, and the absence of foraminiferal forms typical of cool waters, do not support the inference of cool seawaters temperatures attributed to the Early Aalenian, or the global character of the "Comptum cooling event", at least with reference to the Lusitanian Basin.

Keywords:
Ammonite-benthic Foraminifera biostratigraphy
Lower-Middle Jurassic
Toarcian
Aalenian
Lusitanian Basin
Faunal turnover
"Comptum cooling event"

1. Introduction

Ammonites are the best fossil group for dating Jurassic marine sediments, but when these fossils are poorly preserved, scarce or almost impossible to obtain (e.g., in core samples), alternative biostratigraphic scales based on other fossil groups are needed. In recent decades, there have been some attempts to establish biostratigraphic scales based on benthic foraminifera. The precision and validity of such scales is greater when they can be calibrated with accurate biostratigraphic charts based on ammonites, as done in this work. The stratigraphic range of most of the Jurassic foraminiferal species is relatively wide; therefore, identification of bioevents such as first occurrences (First Appearance Datum, FAD), last occurrences (Last Appearance Datum, LAD) or noticeable changes in assemblage diversity or in the relative abundance of some taxa, can be a useful biostratigraphic tool. Hence, the aim of this work is to describe for the first time the detailed co-occurrence of ammonite and benthic foraminiferal assemblages across the Toarcian-Aalenian boundary at the São Gião section (Lusitanian Basin, Central Portugal), and to recognise the corresponding biostratigraphic units, thus contributing to a better calibration of the biostratigraphic scale for the Lower-Middle Jurassic boundary on the basis of different fossil groups.

The São Gião section is a classical outcrop of the Lower-Middle Jurassic boundary in the Lusitanian Basin, where previous works on ammonites were carried out by Mouterde et al. (1979) and Caloo-Fortier (1985). It is one of the few areas in Europe where this time interval is represented by an expanded section, showing exceptional exposure conditions along highly fossiliferous marly-limestones sediments approximately 45 m-thick, displaying a continuous record of ammonites. Moreover, the relevance of the Grammoceratinae content for palaeobiogeographic reconstructions of the western Tethys (Sandoval et al., 2012a), as well as the significant *Pleydellia* and *Leioceras* record, both justified the proposition of the São Gião section as a reference section for the Toarcian-Aalenian boundary in the Lusitanian Basin (Henriques, 1989, 1992, 2000a; Henriques et al., 1996; Goy et al., 2000; Sandoval et al., 2001a; Azerêdo et al., 2003). More recently, other fossil groups in the section have been studied, namely calcareous nannofossils (Henriques and Perilli, 2000), and most particularly benthic foraminifera (Magno et al., 2008; Magno, 2010; Canales et al., 2010). These studies all suggested the importance of analysing the detailed vertical co-occurrence of ammonite and benthic foraminifera assemblages across the Toarcian-Aalenian boundary at the São Gião section, in order to identify major faunal changes both on macrofossil and microfossil assemblages.

The bioevents recognised in the benthic foraminifera record, accurately calibrated here using ammonite-based biostratigraphic units, represent a proxy that can be used to determinate both the age and depositional environment assigned to core samples (Canales et al., 2010). Moreover, they allow the interpretation of previous data on palaeotemperature changes established for neighbouring basins located around the Iberian Plate, e.g., in the southern and northern palaeomargins (O´Dogherty et al., 2006; Sandoval et al., 2008; Gómez et al., 2009), as well as in more distant, boreal regions such as the Hebrides Basin (Price, 2010), where close relationships between major faunal-flora turnovers and isotopic fluctuations in δ^{13}C have been recognised (Aguado et al., 2008; Sandoval et al., 2012b).

2. Geographic and geological settings

The São Gião section is located in the northern sector of the Lusitanian Basin (Central Portugal), at about 5 km to the South-Southwest of Cantanhede village, near Zambujal (coordinates: 40º18’12.63’’N, 8º37’17.58’’W; altitude: 100 m; Fig. 1).The section is composed of greyish marly limestones, more or less compact, in regular beds with thicknesses ranging from 0.10 to 0.30 m, alternating with slightly thicker greyish marl beds organised in shallowing-upward units and deposited in an external marine platform environment. The limestone component progressively increases towards the top of this unit, which corresponds to the upper part of the Póvoa da Lomba Formation (upper Toarcian-upper Aalenian).

The Póvoa da Lomba Formation was firstly informally defined by Barbosa et al. (1988, 2008) as a lithostratigraphic unit named the "Calcários Margosos de Póvoa da Lomba" ("Póvoa da Lomba Marly Limestones"), and later formalised as the Póvoa da Lomba Formation by Azerêdo et al. (2003). It corresponds laterally to the lower part of the Cabo Mondego Formation which outcrops at the west of the basin, the upper part of the Prado Formation outcropping eastwards, and the top of the Fórnea Formation / base of the Barranco de Zambujal Formation which outcrops in the southeast of the basin (Azerêdo et al., 2003; Fig. 2).

3. Material and methods

In order to study the ammonite record, 44 successive bed-by-bed samplings were obtained from 36 marly-limestone beds and 8 marly beds. A total of 447 ammonite specimens were collected and identified according to the systematic classification proposed by Henriques (1992).

A total of 24 marly beds were sampled for the study of the benthic foraminiferal assemblages, taking into account the thickness of each ammonite subzone. For each sample, 300 g were processed in the laboratory using a classical methodology involving a mixture of sodium hydroxide, hydrogen peroxide and water for 2-3 days. Following this, the samples were washed over a column of 1.000, 0.500, 0.250, 0.125 and 0.060 mm mesh sieves. The dry residues were weighed and subsequently picked to obtain the foraminifera using a Wild M-8 binocular microscope. The specimens recovered were classified, at suprageneric and generic rank, using the Loeblich and Tappan (1988) systematic; the Ellis and Messina (1940-1990) foraminifera catalogue was consulted for the specific rank classification. Photographs of the figured specimens were taken at the Centro Nacional de Microscopía Electrónica, Universidad Complutense de Madrid (Spain), using a JEOL-JSM 6400 electronic microscope.

The species richness and relative abundances were calculated for both fossil groups. Species richness is understood as the number of species (or other taxonomical category) in a sampling unit, in relation to the total number of identified species (or other taxa). Relative abundances are expressed as percentages, in relation to the total number of specimens obtained in each assemblage. All the ammonite and foraminifera specimens (including the residues of the samples studied) are stored in the Laboratório de Geologia Sedimentar e Registo Fóssil, Departamento de Ciências da Terra, Faculdade de Ciências e Tecnologia, University of Coimbra (Portugal).

4. Taphonomic considerations

The preservational features of the ammonite assemblages can be characterised according to several taphonomic parameters described for *Tmetoceras* from Iberia (Fernández López et al., 1999a, 1999b) and for other ammonites from the Lower Pliensbachian of Portugal (Fernández López et al., 2000). Marly limestones mainly record resedimented elements, whereas accumulated shells are virtually absent and re-elaborated elements are scarce. Ammonite assemblages are composed of incomplete phragmocones normally filled with sediment and, in general, appear scattered in the sediment, showing no pattern of imbricate or encased grouping. Complete shells are scarce and pyritic internal moulds are only found locally and assigned to marly levels. The degree of ammonite packing – estimated by the difference between the number of specimens and the number of fossiliferous levels divided by the number of fossiliferous levels –, and the ammonite stratigraphical persistence – i.e., the proportion of fossiliferous levels – presents high values (9.15 and 38%, respectively), whereas the degree of taphonomic heritage – i.e., the percentage of re-elaborated elements – is very low to nil.

The ratio between the amount of preserved elements and the amount of species is high (26.3), making specific diversity, i.e., the inverse ratio, relatively low (0.04); adult shells are scarce. These taphonomic features, by disproving sorting processes involving mechanical transport, support the demic nature of the fossil assemblages, as pointed out by Fernández López and Meléndez (1995) for the Phylloceratina and by Fernández López et al. (1999b) for the *Tmetoceras* of the Iberian basins during the Middle Jurassic.

Concerning the benthic foraminifera record, most of the 13.116 specimens recovered are very well preserved. From a taphonomic point of view, only breakages, sedimentary infillings of the chambers, dissolution (partial or even total, as is the case for some representatives of the Family Ceratobuliminidae), distortion and recrystallisation (Herrero and Canales, 2002) were observed in some specimens, but no evidence of any alteration of the assemblages can be inferred. The last two studied samples come from harder sediments and, as a consequence, the surface of the specimens appeared to be covered by calcite crusts, thus hindering their taxonomic identification at specific rank.

5. Results

The co-occurrence of ammonite and benthic foraminiferal assemblages across the São Gião section provides a precise and detailed ammonite-based biostratigraphic zonation as well as an alternative biostratigraphic scale based on benthic foraminifera. In addition, the identification of bioevents, such as FADs, LADs or noticeable changes in assemblages' species richness or in the relative abundance of some taxa in both fossil groups, may prove to be a useful biostratigraphical proxy. Such bioevents are, so far, considered to be of local application. It is expected that future analyses in the same basin or in other basins will allow for correlations between different sections, based on some of these bioevents. Moreover, the taxonomic composition of the assemblages and the recognised bioevents in the São Gião section provide relevant palaeoecological data for ongoing discussions on the relationships between major faunal turnovers and palaeotemperature changes during the Early-Middle Jurassic transition.

5.1. Ammonite and benthic foraminiferal assemblages

The ammonite record of the São Gião section mainly includes some typical northwest European Grammoceratinae (*Catulloceras*, *Cotteswoldia*, *Pleydellia*) in the upper Toarcian, and Leioceratinae (*Leioceras*, *Cypholioceras*) in the lower Aalenian, together with typical Mediterranean Grammoceratinae (*Vacekia*), Tmetoceratinae (*Tmetoceras*) and rare Hammatoceratidae (*Bredya* and *Czerneyiceras*) (Fig. 3). No typically Tethysian phylloceratids were found among the 20 species identified (some of which are represented in Fig. 4).

The foraminiferal assemblages recorded along the stratigraphic interval are very abundant and display a high species richness (Figs. 5, 6). A total of 71 species (some of which are represented in Figs. 7, 8), corresponding to 26 genera and 5 suborders, have been identified, all typical of the Jurassic platforms in the northern hemisphere.

5.1.1. Upper Toarcian, Aalensis Biozone, Mactra Subzone

Samples SG1-SG8; 3.5 m of 0.70 m-thick greyish marls alternating with 0.15 m-thick lenticular greyish marly limestones with abundant ammonite content.

Index fossil: *Pleydellia mactra* (Dumortier).

The ammonite assemblage recognised in this subzone, which corresponds to 6 fossiliferous levels, reveals low number of specimens (16) but a relatively high number of species (5 identified species corresponding to 2 genera). Most specimens correspond to the

Cotteswoldia genus, namely *C. limatula* Buckman, *C. egena* Buckman, and *C. costulata* (Zieten) (representing 38% of the identified specimens), and the *Pleydellia* genus, namely *P. fluens* (Buckman) and *P. subcompta* Branco (also representing 38% of the identified specimens) (Table S1, Appendix A). The latter is a significant component of the recorded assemblages, as it represents earlier *Pleydellia*, thus characterising the subzone, whose base is recognised by the FAD of these forms.

The only foraminiferal assemblage studied from the Mactra Subzone corresponds to sample SG8 (Table S2). A total of 469 specimens were obtained, 434 (93%) of which were identified at specific level. Taking into account the number of grams of picked sediment, in this sample the abundance amounts to 60.5 foraminifera per gram of picked sediment. In this assemblage, 4 suborders (Spirillinina, Miliolina, Lagenina and Robertinina) were identified, in which Lagenina was the most abundant (87%). Spirillinina and Miliolina occur in percentages of less than 4% and Robertinina is known from a single specimen. The total absence, in this assemblage, of representatives of the Textulariina Suborder is notable, given that these are present, even if in small numbers, in Lower-Middle Jurassic foraminiferal assemblages of other coeval basins (Canales and Herrero, 1996, 2000; Canales and Ureta, 1997; Canales, 2001; Canales and Henriques, 2007, 2008; Figueiredo, 2009; Canales et al., 2010; Figueiredo et al., 2010; Guterres, 2010; Magno, 2010; Figueiredo and Guterres, 2012). At generic level, a total of 13 genera were identified, in which *Lenticulina*, with a relative abundance of 77%, clearly predominates. On a specific level, a total of 31 species were identified, of which *Lenticulina polygonata* (Franke) was the most abundant (19%). There was no evidence of any single species dominating over the others (Table S2).

5.1.2. Upper Toarcian, Aalensis Biozone, Aalensis Subzone

Samples SG9-SG33; 7.5 m of greyish marls with thicknesses varying from 0.15 to1.10 m, alternating with 0.15 m-thick of bioturbated greyish marly limestones, displaying very abundant, sometime pyritised ammonite internal moulds.

Index fossil: *Pleydellia aalensis* (Zieten).

Other biostratigraphic units have been proposed for the upper part of the Aalensis Biozone. Page (2003) uses *P. fluitans* as index for the Fluitans Subzone. However, *P. fluitans* has a scarce record in the Lusitanian Basin and, as pointed by Elmi et al. (1997: p. 34), “sa position stratigraphique au sein de la zone à Aalensis ne nous paraît pas bien établie, ce qui justifie son abandon en tant qu’indice”. Concerning the Lugdunensis Subzone, it has been established due to traditional misinterpretations of *P. aalensis* (Zieten) by some authors.

According to Elmi et al. (1997: p. 34), “L’école française utilisait une sous-zone à Aalensis pour cet intervalle de temps [Sous-zone à Lugdunensis] en faisant référence à l’espèce figurée par Dumortier (1874, pl. L, fig. 1-3) qui est bien différente du type de Zieten […]. Afin d’éviter de pérenniser les confusions, nous proposons le nouveau nom de *Pleydellia (Walkericeras) lugdunensis* […]” for the French forms of *Walkericeras*, previously interpreted as *P. aalensis sensu* Dumortier *non* Zieten, the original author of the *aalensis* species. But the Aalensis Biozone, based on the occurrence of its index fossil – *P. aalensis* (Zieten), i.e., specimens displaying rounded umbilical wall and variable ribbing during ontogeny, according to the original interpretation by Zieten (1830) –, is perfectly recognizable in several basins around the Iberian Plate, where correlation has been already established (e.g., Goy et al., 2000), including at Fuentelsaz, the Aalenian GSSP.

The ammonite assemblage recognised in the Aalensis Subzone of the Aalensis Biozone, which corresponds to 12 fossiliferous levels, reveals high abundance (140 specimens, 118 of which identified at the species level) and high number of taxa (10 identified species; 4 identified genera) (Table S3). The base of the subzone is defined by the FAD of the index species *P. aalensis* (Zieten, 1830 *non* Dumortier, 1874), which dominates amongst the fauna (39 specimens representing 33% of the identified specimens), in association with *P. folleata* (Buckman). The base of the subzone also records the last occurrence of *P. subcompta* Branco and *P. fluens* (Buckman). *Cotteswoldia costulata* (Zieten) (18% of the identified speciemsn), *C. limatula* Buckman and *C. egena* Buckman, which occur in the previous subzone, still remain here. Last *Catulloceras* occur together with the first *Tmetoceras*; *Vacekia sourensis* (Perrot) and early striate *Vacekia*, like *V. striata* Henriques (Sandoval et al., 2012a), are also relatively abundant (10% of the identified specimens). The marly levels of the thick SG14 bed reveal a great abundance of indeterminate pyritised *Cotteswoldia* and *Pleydellia* nucleus (Table S3).

Four foraminiferal assemblages (samples SG12, SG18, SG24 and SG32) from the Aalensis Subzone were studied (Table S4). A total of 2.006 specimens were recovered, 1.922 of which were identified at the specific level. The average abundance in these assemblages amounts to 94 foraminifera per gram of picked sediment. At suborder level, representatives of Textulariina, Spirillinina, Miliolina, Lagenina and Robertinina were identified, within which Lagenina was the most abundant (82% of the assemblage), followed by Miliolina (15%). This fact is remarkable, since representatives of this suborder, when present in Toarcian-Aalenian foraminiferal assemblages, are usually very rare (Herrero and Canales, 1997; Canales and Herrero, 2000; Canales, 2001; Henriques and Canales, 2007, 2008; Figueiredo, 2009;

Figueiredo et al., 2010; Figueiredo and Guterres, 2012). The remaining suborders show relative abundances of less than 2%. At generic level, 18 genera were identified in these assemblages and, again, the representatives of the genus *Lenticulina*, representing 69% of the assemblage, were dominant. Moreover, the large amount of specimens corresponding to the genus *Vinelloidea* (Miliolina Suborder), whose relative abundance amounts to 15%, is noticeable. A great number of species (45 in total) have been identified in these assemblages. Among them, *Lenticulina toarcense* Payard is the most abundant (18% of the assemblage), but no single species was markedly dominant (Table S4).

5.1.3. Lower Aalenian, Opalinum Biozone, Opalinum Subzone

Samples SG34-SG54; 8 m of alternating greyish marly limestones in 1 m-thick beds, and thin micritic marly limestones in 0.20 m-thick beds, including very abundant, sometime pyritised ammonite internal moulds.

Index fossil: *Leioceras opalinum* (Reinecke).

The ammonite assemblage recognised in this subzone corresponds to 7 fossiliferous levels, displaying the greatest abundance and species richness in the whole section (153 specimens; 45 identified at species level; 6 identified species; 5 identified genera; Table S5). The base of the subzone is characterised by the FAD for *Leioceras opalinum* (Reinecke), which appears in association with *Pleydellia* representatives until bed SG35, where the LAD for this taxon is recorded (Fig. 3). *P. aalensis* (Zieten), *P. folleata* (Buckman), *P. lotharingica* (Buckman) and *P. fluitans* (Dumortier) co-exist at the base with the first Leioceratinae, representing 48% of the total recorded assemblages in this subzone, followed by *Vacekia* representatives, mainly *V. striata* Henriques (10%). *Cypholioceras lineatum* (Buckman), *Leioceras opalinum* (Reinecke) and indeterminate species of both genera represent only ~11% of the recorded ammonite specimens. Rare *Czerneyiceras* also feature in the ammonite assemblages of this unit, in which the LAD of several taxa have been identified – namely *Pleydellia*, *Cotteswoldia* and *Catulloceras* – together with the FAD of others – *Cypholioceras*, *Leioceras* and *Czernyeiceras* –, corresponding to an important ammonite turnover from the typical Late Toarcian taxa to the characteristic early Aalenian taxa. This turnover, which can be accurately assigned to the Opalinum Subzone, is particularly well documented by the SG35 assemblage in the São Gião section (Table S5).

Seven foraminiferal assemblages from the Opalinum Subzone were studied (samples SG34, SG36, SG38, SG44, SG48, SG52 and SG54; Table S6). A total of 3.285 specimens were recovered, 3.012 of which have been identified at the specific level. The average abundance in these assemblages reaches 74 foraminifera per gram of picked sediment. As in the previous subzone, 5 suborders were identified, namely Textulariina, Spirillinina, Miliolina, Lagenina and Robertinina, and again, Lagenina is the dominant suborder (91%), followed by Miliolina (4%) and Spirillinina (3%). TheTextulariina and Robertinina are very rare (<2%). A total of 19 genera were identified, within which representatives of *Lenticulina* genus still predominate. Within the unit, a total of 53 species were identified, which exceeds the number obtained for the Aalensis Subzone. There is no evidence for the dominance of any single species, although the most abundant is *Lenticulina helios* (Terquem), with a relative abundance of 19% (Table S6).

5.1.4. Lower Aalenian, Opalinum Biozone, Comptum Subzone

Samples SG55-SG119; 28 m-thick of greyish marls of irregular thickness ranging from 0.20 to 2 m, alternating with limestones, which are marly and grey at the base, becoming whiter and more micritic towards the top of the succession.

Index fossil: *Cypholioceras comptum* (Reinecke).

The ammonite assemblage recognised in this subzone, which corresponds to 20 fossiliferous levels, reveals relatively high number of specimens (138 specimens; 70 identified at the species level) and high number of taxa (8 identified species belonging to 4 different genera and 2 indeterminate species, one of *Bredyia* and another of *Czernyeiceras*) (Table S7). The base of the subzone is defined by the FAD of the fossil index, associated to other species of the genus *Cypholioceras* – *C. opaliniforme* (Buckman) and *C. lineatum* (Buckman), representing 27% of the identified specimens –, and forms of *Leioceras* ranging from the striated *L. opalinum* (Reinecke) to the costulated *L. costosum* (Quenstedt), which represent 20% of the identified specimens. All Leioceratinae disappear at SG107, where the facies abruptly changes to micritic white limestones. *Vacekia striata* Henriques and *V. sourensis* (Perrot), as well as *Tmetoceras scissum* (Benecke) persist within this subzone, the former being quite significant (26% of the identified specimens) within the unit as a whole, and particularly when Leioceratinae are less abundant or absent (Table S7).

Taking the significant development of the Comptum Subzone in the São Gião section into account, 12 foraminiferal assemblages were studied (samples SG56, SG62, SG64, SG68, SG74, SG78, SG86, SG90, SG92, SG96, SG108 and SG112; Table S8). A total of 7.363 specimens were recovered, 7.071of which were identified at specific level. Again, specimens corresponding to the Textulariina, Spirillinina, Miliolina, Lagenina and Robertinina suborders were obtained, with the Lagenina Suborder dominating (76%). Representatives of the

Miliolina Suborder show a relative abundance of 19%. Again, the representatives of this suborder are more frequent than in coeval Upper Toarcian-Lower Aalenian Iberian sections (Herrero and Canales, 1997; Canales and Herrero, 2000; Canales, 2001; Henriques and Canales, 2007, 2008; Figueiredo, 2009; Figueiredo et al., 2010; Figueiredo and Guterres, 2012). In these assemblages, the representatives of the remaining suborders are rare and all display relative abundances <3%, or even <1% in the case of Robertinina. A total of 24 genera were identified, with the representatives of the genus *Lenticulina* again presenting the highest relative abundance (56%) and dominating over the remaining genera. The relative abundance of other genera such as *Vinelloidea* (9%), *Ophthalmidium* (9%), *Nodosaria* (6%), *Astacolus* (6%), *Prodentalina* (4%) and *Ammobaculites* (2%) is also notable, since they were much rarer in previously studied assemblages. Finally, a total of 63 species were identified, of which *Lenticulina helios* (Terquem) is the most abundant (13%) (Table S8).

5.2. Biostratigraphic significance of the recorded assemblages

The ammonite record (447 specimens, 20 species, 9 genera) for the São Gião section has enabled 4 biostratigraphic units to be recognised: the Mactra and Aalensis subzones of the Aalensis Biozone in the Upper Toarcian, and the Opalinum and Comptum subzones of the Opalinum Biozone in the Lower Aalenian (Fig. 3). This biostratigrahic zonal scheme has been already recognised in the Lusitanian Basin, as well as in other coeval basins of the Iberian Peninsula (Henriques, 1995; Henriques et al., 1996; Sandoval et al., 2001a), namely at the Fuentelsaz section (Iberian Cordillera), where the Aalenian GSSP has been established (Cresta et al., 2001).

From a biostratigraphic point of view, the benthic foraminifera identified in São Gião (13.116 specimens, 71 species, 26 genera, 5 suborders) allow for the recognition of the *Astacolus dorbignyi* Zone – in the sense of the Dorbignyi Zone proposed by Canales (2001) in the Basque-Cantabrian Basin (Northern Spain) for the Lower-Middle Jurassic transition –, with *Astacolus dorbignyi* (Roemer) serving as the index fossil (Fig. 6). This zone has also been recognised in other sections of the Lusitanian Basin (Figueiredo, 2009; Guterres, 2010; Magno, 2010; Canales et al., 2010; Figueiredo et al., 2010; Figueiredo and Guterres, 2012). Its lower boundary is marked by the first record of the index species, previously unrecognised in the Lusitanian Basin, whose upper boundary coincides with the first record of *Lenticulina quenstedti* (Gümbel), the index species for the *Lenticulina quenstedti* Zone, which has been characterised as belonging to the upper part of the Gigantea Subzone (Bradfordensis Biozone, Middle Aalenian) at the Bajocian GSSP in the Murtinheira section (Portugal) (Canales and Henriques, 2013).

6. Discussion

The composition of the ammonite assemblages in the São Gião section is cosmopolitan in nature, with a constant and continuous record of both northwest European taxa – thus allowing the recognition of the standard biozonation established for the Lower-Middle Jurassic transition –, together with typical Mediterranean taxa – thus increasing its correlation potential with sections located in both provinces. Both reproduce the general trends already recognised in other coeval sections of the Lusitanian Basin and of the Iberian Plate (Henriques, 1989, 1992, 1995, 2000a, 2000b; Henriques et al., 1996; Goy et al., 2000; Sandoval et al., 2001a; Azerêdo et al., 2003), although the ammonite content displays some peculiarities of stratigraphic and palaeoecological relevance, as discussed below (Sections 6.1. and 6.3.).

The general composition of the foraminiferal assemblages recorded in São Gião is also comparable with other coeval sections, not only in the Lusitanian Basin (Canales and Henriques, 2007, 2008; Figueiredo, 2009; Figueiredo et al., 2010; Guterres, 2010; Magno, 2010; Figueiredo and Guterres, 2012), but also in other Iberian sections (Canales and Herrero, 1996, 2000; Canales and Ureta, 1997; Herrero and Canales, 1997; Canales et al., 2000; Canales, 2001). However, like the ammonite fauna, the foraminiferal assemblages display some peculiarities in terms of their species richness and the main components of the assemblages, which are also of stratigraphic and palaeoecological relevance, as discussed below (Sections 6.2. and 6.3.).

6.1. Ammonite record and stratigraphic implications

With regard to the stratigraphic range of the index species *Pleydellia aalensis* (Zieten) and *Leioceras opalinum* (Reinecke), their co-existence at the base of the Opalinum Subzone has been clearly confirmed, corresponding to a bioevent recognisable at basinal scale (Fig. 4(C)). The base of the Opalinum Subzone therefore has to be established by the FAD of the latter, and not by its FAD concomitant with the LAD of *Pleydellia aalensis* (Zieten) (Fig. 6). Similarly, the co-occurrence of *Leioceras opalinum* (Reinecke) and the FAD of *Cypholioceras comptum* (Reincke) at the base of the Comptum Subzone ignores the extinction of the former as a criterion for recognising the Opalinum-Comptum subzone boundary (Fig. 4(J)).

The increase in the relative abundance of *Vacekia* representatives in the upper part of the Comptum Subzone is a relevant bioevent, at least with regional value, allowing the subzone to be recognised in sections of the Lusitanian Basin where the last Leioceratinae representatives are generally rare or absent (Fig. 3).

6.2. Foraminiferal record and stratigraphic implications

With regard to benthic foraminifera species richness, a total of 57 species where identified in the stratigraphic interval studied in the Zambujal de Alcaria section (Figueiredo, 2009; Figueiredo et al., 2010), 45 in the Maria Pares section (Guterres, 2010; Figueiredo and Guterres, 2012), and 35 in the Murtinheira section (Canales and Henriques, 2008), all of which lie in the Lusitanian Basin. In addition, a total of 50 species where obtained from different sections of the Basque-Cantabrian Basin in Northern Spain (Canales, 2001). In the Moyuela section, located in the Iberian Range (Spain), 47 species were identified along the Upper Toarcian and Lower Aalenian transition (Canales and Herrero, 2000), whilst in the Fuentelsaz section (Aalenian GSSP), also located in the Iberian Range, a total of 62 species were obtained (Herrero and Canales, 1997). As a consequence, and taking into account the fact that a total of 71 species have been identified in São Gião, this section is the most diverse of the Iberian basins in terms of this stratigraphic interval.

Regarding the taxonomical composition of the assemblages, as commonly occurs in Jurassic foraminiferal assemblages from the Boreal Realm, *Lenticulina* (Lagenina Suborder) is the most abundant genus. In the São Gião section, the most abundant species of this genus in almost all of the assemblages is *L. helios* (Terquem). Canales et al. (2010) have pointed out that the different species of *Lenticulina* recorded in the Lower-Middle Jurassic transition in several sections of the Lusitanian Basin show variations in their relative abundances which can be related to the facies where they developed. Thus, *L. muensteri* (Roemer) is relatively more abundant in facies corresponding to the deeper part of the platform, whilst *L. helios* (Terquem) reaches maximum relative abundance in the middle platform, and *L. toarcense* Payard is most abundant in facies corresponding to the shallower part (the inner platform).

Other Lagenina genera with unusually high relative abundance, such as *Prodentalina*, *Nodosaria* and other elongated forms, corresponding to shallow infaunal morpho-groups and indicating good levels of nutrients and oxygenation in the infaunal microhabitats (Reolid et al., 2012), have been recorded in the Comptum Subzone. The abundant record of representatives of the Miliolina Suborder, which are present in almost all the studied assemblages, and are unusually frequent in the Aalensis and in the upper part of the Comptum subzones, is also notable.

The foraminiferal assemblages recorded are abundant and very diverse. Within the studied time span, there are no significant arrivals or disappearances of taxa – the whole stratigraphic interval corresponds to a single foraminiferal zone: the *Astacolus dorbignyi* Zone. For this reason, a total of 11 bioevents, based on FAD, LAD or change in the observed abundance of some taxon or in assemblage diversity have been established, representing biostratigraphical proxies generally of local application (Fig. 6). Nevertheless, some of them, e.g., the increase in the relative abundance of *Lenticulina exgaleata* Dieni from the upper part of the Opalinum Subzone to the lower part of the Comptum Subzone, have also been recognised in other coeval sections in the Lusitanian Basin (Canales and Henriques, 2008; Figueiredo, 2009; Figueiredo et al., 2010; Guterres, 2010), thus demonstrating regional value. The FAD of *Nodosaria hortensis* Terquem in the Aalensis Subzone and the marked increase in the relative abundance of *Ophthalmidium* representatives in the lower part of the Comptum Subzone have been also recognised in the Zambujal de Alcaria Section (Figueiredo, 2009; Figueiredo et al., 2010). The increase observed in the relative abundance of the representatives of the Textulariina Suborder, as well as in *Eoguttulina liassica* (Strickland) in the upper part of the Comptum Subzone, have also been recognised in the Murtinheira section (Canales and Henriques, 2008).

6.3. Faunal turnovers and seawater palaeotemperatures

A previous study on morphological changes observed in ammonites at the Lias-Dogger boundary, questioned the existence of a faunal crisis during the Late Toarcian-Early Aalenian times (Neige et al., 2001). The ammonite composition of the assemblages throughout the Upper Toarcian-Lower Aalenian record for the São Gião section also shows a virtually constant rate of faunal turnover, i.e., no drastic changes in the number of originations and extinctions between ammonite biozones, unlike the coeval record described for the Betic Cordillera. The Toarcian-Aalenian ammonite record is represented in this case by a major faunal turnover which has been correlated with a sea-level regressive phase (Sandoval et al., 2001b) and relatively low $\delta^{13}C$ values for bulk carbonates in the Upper Toarcian, followed by a moderate positive excursion of the $\delta^{13}C_{carb}$ in the Comptum Subzone (Sandoval et al., 2008). This “Comptum cooling event” was also noted by Gómez et al. (2009) for the Basque-Cantabrian Basin (Northern Spain), in relation to a major faunal turnover in the ammonite and foraminiferal records; a seawater temperature of 15.7ºC based on $\delta^{18}O_{bel}$ has been proposed for this time interval. Price (2010) proposes a seawater temperature of 15-22ºC for the Early Aalenian with rapid cooling to a minimum of 7ºC for the Comptum Subzone based on the positive isotopic excursion recognised in the $\delta^{18}O_{bel}$ curves for the Aalenian and Bajocian of Scotland; he therefore supports the global range of the "Comptum cooling event". However, the Comptum Subzone of the São Gião section is characterised by the co-occurrence of northwest European Leioceratinae taxa and Mediterranean Grammoceratinae, namely the dominant *Vacekia striata* Henriques, which may amount to 30% of the total identified specimens within the whole unit, a feature also recognised at basinal scale (Sandoval et al., 2012a).

Among the foraminifers, miliolids, generally interpreted as typical of shallow waters (Copestake and Johnson, 1981; Haynes, 1981; Stam, 1985; Murray, 1989), have a continuous and relatively abundant record in this section. This group amounts to 19% of the total assemblage from the Comptum Subzone in São Gião, but is rare in the Aalenian GSSP (Herrero and Canales, 1997), and absent in all coeval sections of the Basque-Cantabrian Basin (Canales, 2001) and the Northern Iberian Range (Canales and Herrero, 2000). In the Lusitanian Basin, Miliolina are rare in distal and proximal facies (Canales and Henriques, 2008; Figueiredo, 2009; Figueiredo et al., 2010), but represent 7% of the relative abundance in intermediate facies (Guterres, 2010; Figueiredo and Guterres, 2012), such as those of the São Gião section. Regarding the taxonomical composition of the foraminiferal assemblages described in the Basque-Cantabrian Basin (Northern Spain), and in relation to the "Comptum cooling event", 14 species present their FAD within this time interval (Gómez et al., 2009). Most of them, apparently typical of cool waters, are absent in São Gião and, whenever present, record is scarce, both in terms of stratigraphic distribution and relative abundance.

As a consequence, the results obtained from the compositional analysis of the ammonite and foraminiferal assemblages recorded in the São Gião section do not support the inferred cooling trend to minimum seawater temperatures, or the global character of the "Comptum cooling event". Local reasons must be cited in order to justify the warmer seawater temperature trend in the Lusitanian Basin as inferred here from the ammonite and foraminiferal records, specifically in relation to the palaeogeographic location of the basin within the context of the opening of the North Atlantic Ocean (García-Frank et al., 2008) and/or the hypothetical connection between Western Tethys and the Eastern Pacific through the Hispanic Corridor (Arias, 2006, 2007; Sandoval et al., 2012a). Hydrothermal activity and/or changes in oceanic circulation patterns are plausible explanations for the occurrence of warmer seawater temperatures in this sector of the Lusitanian Basin, as opposed to the inferred cool seawater accepted for neighbouring basins.

7. Conclusion

The first study of the co-occurrence of ammonite and benthic foraminiferal assemblages across the São Gião section (Central Portugal) represents a contribution to knowledge of this reference section for the Lower-Middle Jurassic boundary in the Lusitanian Basin. The analysis of the macro- and microfossil assemblages in this expanded section, both correlatable with the Aalenian GSSP at the Fuentelsaz section (Iberian Cordillera, Spain; Cresta et al., 2001), improves the calibration of the biostratigraphic scale for the Lower-Middle Jurassic transition based on these fossil groups, making benthic foraminifera a particularly useful biostratigraphical proxy when ammonites are poorly preserved, scarce or almost impossible to obtain (e.g., in core samples).

A total of 447 well-preserved ammonite specimens and 13.116 foraminifers have been studied and no evidences of taphonomic processes that could change the original assemblages were detected. From a taxonomic point of view, the ammonite record of the São Gião section mainly includes some typical northwest European Grammoceratinae (*Catulloceras, Cotteswoldia, Pleydellia*) in the Upper Toarcian, and Leioceratinae (*Leioceras, Cypholioceras*) in the Lower Aalenian, together with typical Mediterranean Grammoceratinae (*Vacekia*), Tmetoceratinae (*Tmetoceras*) and rare Hammatoceratidae (*Bredya* and *Czerneyiceras*). No typically Tethysian phylloceratids were found among the 20 identified species (corresponding to 9 genera), but the relative abundance of Grammoceratinae throughout the studied time interval is noticeable, namely *Vacekia striata* Henriques, which accounts for 26% of the total identified specimens in the Comptum Subzone. Regarding foraminifera, the recorded assemblages are very abundant, being the most diverse in the Iberian Peninsula for this time interval. A total of 71 species, corresponding to 26 genera and 5 suborders have been identified, all typical of the Jurassic platforms of the northern hemisphere. Among the recognised suborders, Lagenina are dominant, *Lenticulina* being the best represented genus and *Lenticulina helios* (Terquem) the most abundant species. In addition, representatives of the Miliolina Suborder are also unusually frequent.

The ammonite record of the São Gião section has enabled 4 ammonite-based biostratigraphic units to be recognised (Mactra and Aalensis subzones of the Aalensis Biozone in the Upper Toarcian, and Opalinum and Comptum subzones of the Opalinum Biozone in the Lower Aalenian). With regard to benthic foraminifera, the taxa identified have enabled the *Astacolus dorbignyi* Zone to be identified, as well as 11 bioevents based on FAD, LAD, and changes in the relative abundance of certain taxa or changes in species richness in the recorded assemblages. The constant and continuous ammonite record of northwest European taxa, together with the typical Mediterranean taxa throughout the section, the relatively high abundance of Miliolina representatives, which are usually interpreted as typical of shallow waters, and the absence of typical cool water forms, do not concur with the inferred cooling of seawater temperatures assigned to the Early Aalenian, or the global nature of the "Comptum cooling event".

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Appendix A. Supplementary information

Supplementary information (Tables S1-S8) associated with this article can be found, in the online version, at:

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Figure captions

Figure 1. Geological map of the Lusitanian Basin (West of the Iberian Peninsula) showing the Jurassic outcrops and location of the São Gião section (modified after Figueiredo, 2009).

Figure 2. Synthetic lithostratigraphic chart for the Upper Triassic and Lower and Middle Jurassic of the Lusitanian Basin, showing the position of the São Gião section (modified after Azerêdo et al., 2003).

Figure 3. Lithological succession in the São Gião section, showing the ammonite-based biostratigraphic units and the occurrence and relative abundance (black dots with different diameter) of the identified ammonite taxa along the section.

Figure 4. Upper Toarcian and Lower Aalenian selected ammonites recorded in the São Gião section. **A.** *Pleydellia subcompta* Branco, SG6.1. **B.** *Pleydellia aalensis* (Zieten), SG9.1. **C.** *Pleydellia aalensis* (Zieten), SG35.1. **D.** *Pleydellia folleata* (Buckman), SG11.4. **E.** *Pleydellia fluitans* (Dumortier), SG35.50. **F.** *Pleydellia lotharingica* (Buckman), SG35.5. **G.** *Pleydellia lotharingica* (Buckman), SG35.71. **H.** *Pleydellia folleata* (Buckman), SG27.17. **I.** *Cotteswoldia egena* Buckman, SG22.1. **J.** *Cotteswoldia limatula* Buckman, SG22.2. **K.** *Leioceras opalinum* (Reinecke), SG55.49. **L.** *Leioceras costosum* (Quenstedt), SG55.31. **M.** *Leioceras costosum* (Quenstedt), SG103.1. **N.** *Cypholioceras lineatum* (Buckman), SG39.4. **O.** *Cypholioceras comptum* (Reinecke), SG55.32. **P.** *Vacekia striata* Henriques, SG43.4. **Q.** *Vacekia sourensis* (Perrot), SG55.1. **R.** *Vacekia striata* Henriques, SG102.1. **S.** *Tmetoceras scissum* (Benecke), SG33.6. **T.** *Tmetoceras scissum* (Benecke), SG66.1. **U.** *Bredyia* sp., SG83.1. A: Toarcian, Aalensis Biozone, Mactra Subzone; B, D, H-J: Toarcian, Aalensis Biozone, Aalensis Subzone; C, E-G, N, P, S: Aalenian, Opalinum Biozone, Opalinum Subzone; K-M, O, Q, R, T, U: Aalenian, Opalinum Biozone, Comptum Subzone. Scale bar: 2 cm.

Figure 5. Occurrence and relative abundance of some of the foraminiferal taxa recorded in the studied stratigraphic interval.

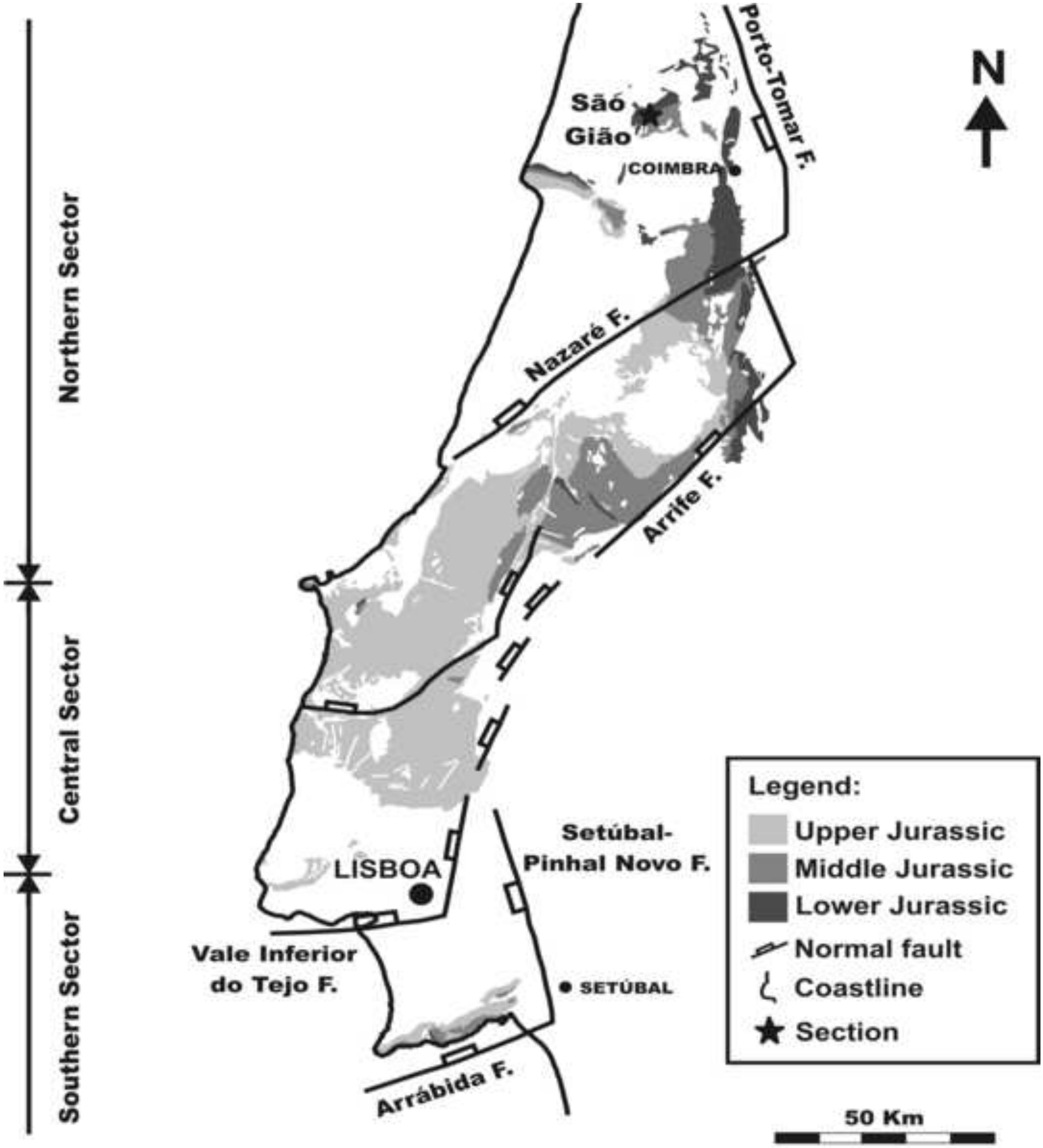
Figure 6. Occurrence and relative abundance of some of the foraminiferal taxa recorded in the studied stratigraphic interval (left), and main bioevents based on ammonites and

foraminifers identified along the Lower/Middle Jurassic transition in the São Gião section (right).

Figure 7. Upper Toarcian and Lower Aalenian selected foraminifera (suborders Textulariina, Spirillinina, Miliolina and Lagenina) recorded in the São Gião section. **A.** *Thurammina jurensis* (Franke), SG56.51.211. **B.** *Tolypammina flagellum* Terquem, SG48.103.263. **C.** *Ammobaculites coprolithiformis* (Schwager), SG86.104.264. **D.** *Ammobaculites fontinensis* (Terquem), SG74.52.212. **E.** *Ammobaculites vetustus* (Terquem and Berthelin), SG86.121.281. **F.** *Trochammina* cf. *canningensis* Tappan, SG64.105.265. **G.** *Spirillina numismalis* Terquem and Berthelin, SG54.55.215. **H.** *Spirillina orbicula* Terquem and Berthelin, SG48.54.214. **I.** *Vinelloidea tibia* (Terquem and Berthelin), SG64.122.282. **J.** *Ophthalmidium northamptonensis* Wood and Barnard, SG64.57.217. **K.** *Prodentalina* cf. *fragilis* (Terquem), SG64.124.284. **L.** *Prodentalina* cf. *guembeli* (Schwager), SG64.67.227. **M.** *Prodentalina pseudocommunis* (Franke), SG32.65.225. **N.** *Prodentalina subsiliqua* (Franke), SG62.66.226. **O.** *Falsopalmula jurensis* (Franke), SG86.69.229. **P.** *Falsopalmula obliqua* (Terquem), SG54.70.230. **Q.** *Nodosaria fontinensis* Terquem, SG74.72.232. **R.** *Nodosaria hortensis* Terquem, SG56.73.233. **S.** *Nodosaria liassica* Barnard, SG54.4.234. **T.** *Nodosaria pseudoregularis* Canales, SG96.125.285. **U.** *Nodosaria pulchra* (Franke), SG86.76.236. **V.** *Nodosaria simoniana* d'Orbigny, SG90.110.270. **W.** *Nodosaria torulosi* Frentzen, SG86.111.271. **X**. *Pseudonodosaria vulgata* (Bornemann), SG96.126.286. **Y.** *Lenticulina bochardi* (Terquem), SG86.127.287. A, C-G, I-L, N-Y: Aalenian, Opalinum Biozone, Comptum Subzone; B, H: Aalenian, Opalinum Biozone, Opalinum Subzone; M: Toarcian, Aalensis Biozone, Aalensis Subzone. Scale bars: 100 μm.

Figure 8. Upper Toarcian and Lower Aalenian selected foraminifera (suborders Lagenina and Robertinina) recorded in the São Gião section. **A.** *Lenticulina constricta* (Kaptarenko-Chernousova) *sensu* Jendryka-Fuglewicz, SG68.80.241. **B.** *Lenticulina exgaleata* Dieni, SG54.81.241. **C.** *Lenticulina helios* (Terquem), SG32.82.242. **D.** *Lenticulina muensteri* (Roemer), SG8.83.243. **E.** *Lenticulina polygonata* (Franke), SG48.84.244. **F.** *Lenticulina toarcense* Payard, SG62.129.289. **G.** *Astacolus dorbignyi* (Roemer), SG56.130.290. **H.** *Astacolus scalptus* (Franke), SG64.88.248. **I.** *Astacolus vetustus* (d'Orbigny), SG34.113.273. **J.** *Marginulina* aff. *ambigua* (Schwager), SG62.90.250. **K.** *Marginulina scapha* (Lalicker), SG52.91.251. **L.** *Citharina clathrata* (Terquem), SG38.92.252. **M.** *Citharina colliezi* (Terquem), SG78.93.253. **N.** *Citharina* cf. *ornithocephala* (Wiśniowski), SG64.95.255. **O.**

Planularia beierana (Gümbel), SG32.115.275. **P.** *Planularia protracta* (Bornemann), SG48.98.258. **Q.** *Eoguttulina liassica* (Strickland), SG64.99.259. **R.** *Ramulina* cf. *spandeli* Paalzow, SG64.100.260. **S.** *Bullopora rostrata* Quenstedt, SG32.102.262. **T.** Internal mould of a specimen belonging to the Family Ceratobuliminidae, SG56.116.276. A, F-H, J, K, M, N, Q, R: Aalenian, Opalinum Biozone, Comptum Subzone; B, E, I, L, P, T: Aalenian, Opalinum Biozone, Opalinum Subzone; C, O, S: Toarcian, Aalensis Biozone, Aalensis Subzone; D: Toarcian, Aalensis Biozone, Mactra Subzone. Scale bars: 100 μm.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Southern Sector
São Gião
COIMBRA
Porto-Tomar F.
N
Nazaré F.
Arrife F.
LISBOA
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Pinhal Novo F.
Vale Inferior
do Tejo F.
SETÚBAL
Arrábida F.
Legend:
Upper Jurassic
Middle Jurassic
Lower Jurassic
Normal fault
Coastline
Section
50 Km

Figure 2
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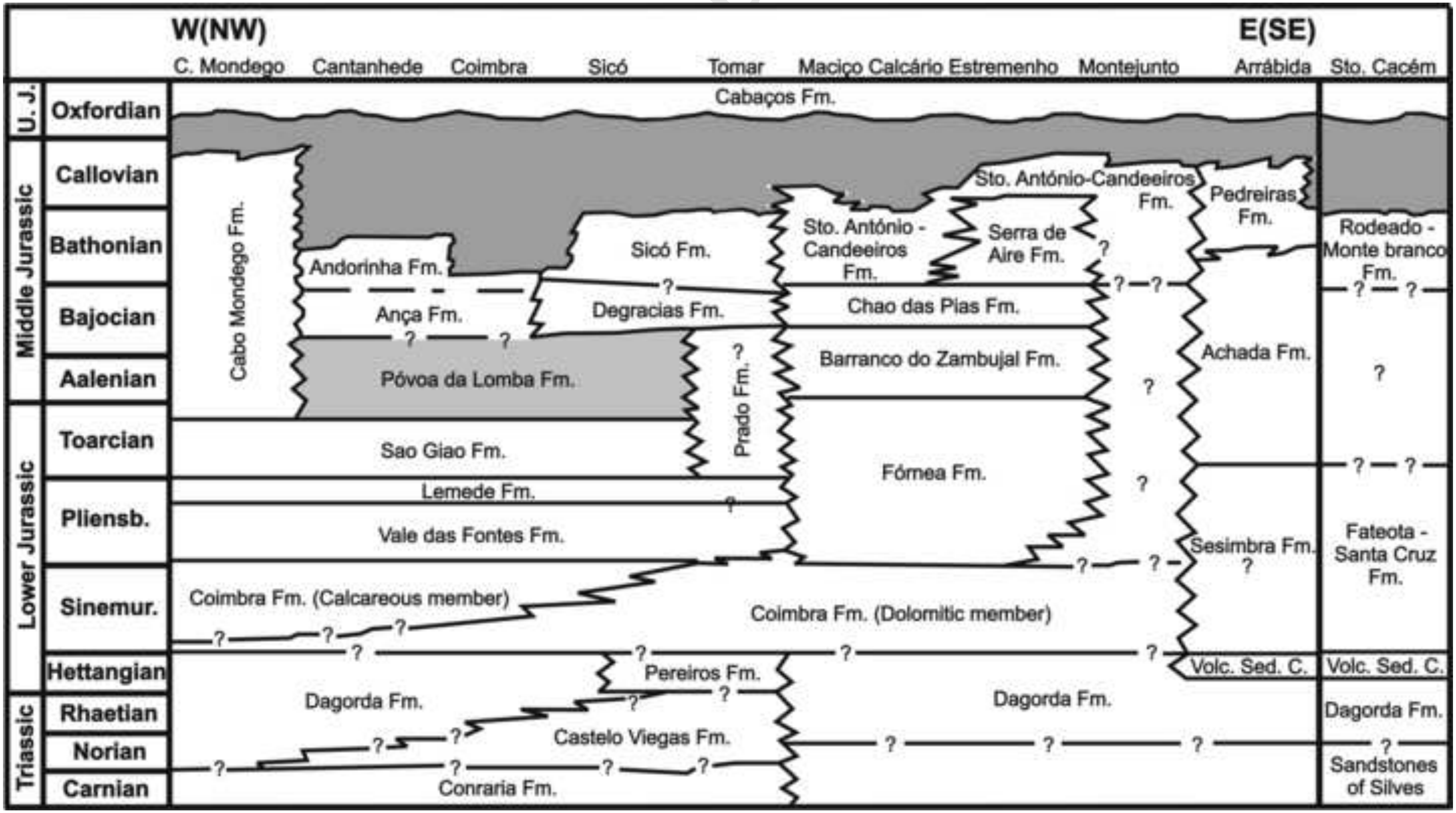

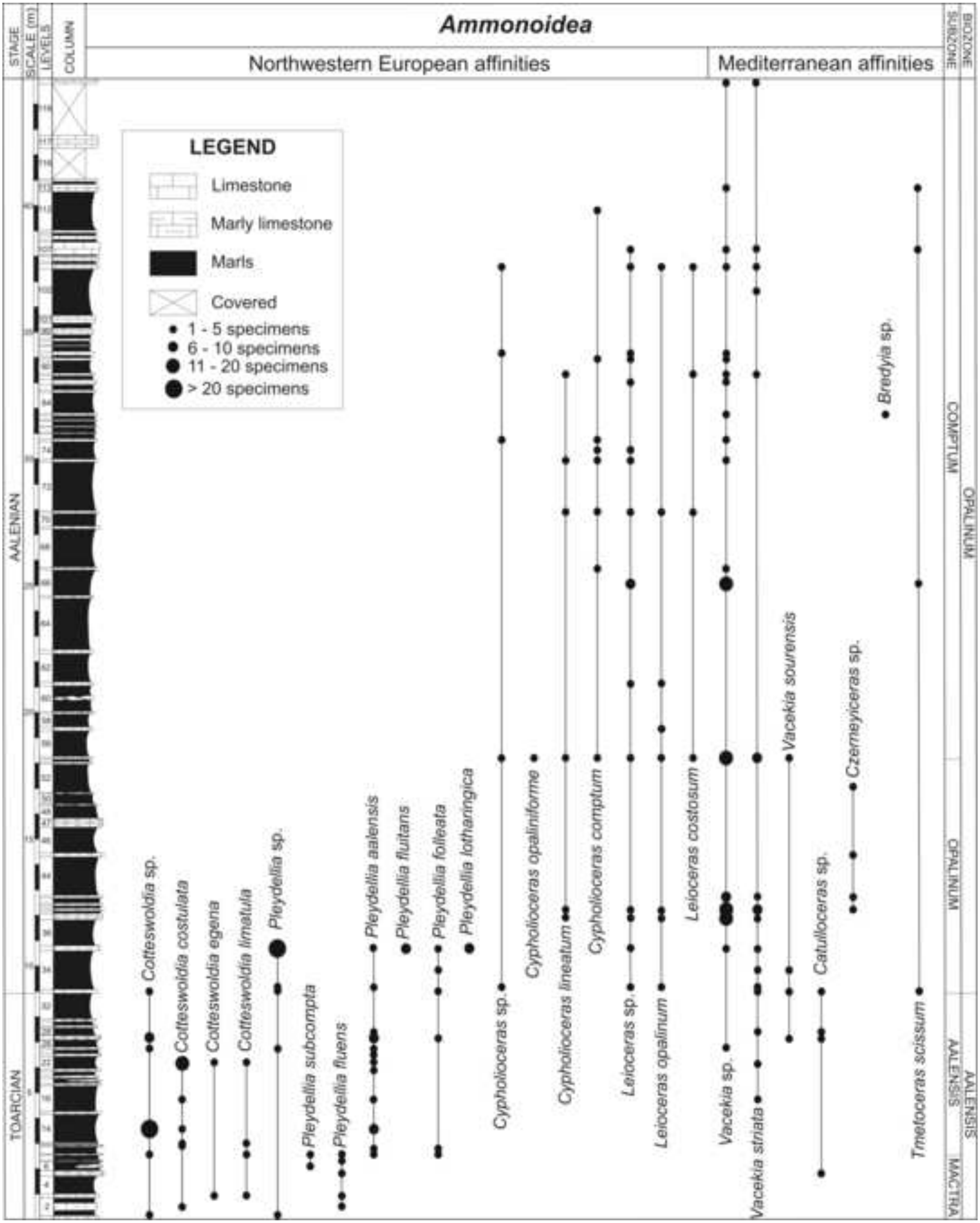
Ammonoidea
Northwestern European affinities
Mediterranean affinities
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LEVELS
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BIOZONE
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Marls
Covered
1 - 5 specimens
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11 - 20 specimens
> 20 specimens
TOARCIAN
AALENIAN
MACTRA
AALENSIS
OPALINUM
COMPTUM
Cotteswoldia sp.
Cotteswoldia costulata
Cotteswoldia egena
Cotteswoldia limatula
Pleydellia sp.
Pleydellia subcompta
Pleydellia fluens
Pleydellia aalensis
Pleydellia fluitans
Pleydellia folleata
Pleydellia lotharingica
Cypholioceras sp.
Cypholioceras opaliniforme
Cypholioceras lineatum
Cypholioceras comptum
Leioceras sp.
Leioceras opalinum
Leioceras costosum
Vacekia sp.
Vacekia striata
Vacekia sourensis
Catulloceras sp.
Czerneyiceras sp.
Bredyia sp.
Tmetoceras scissum

Figure 4
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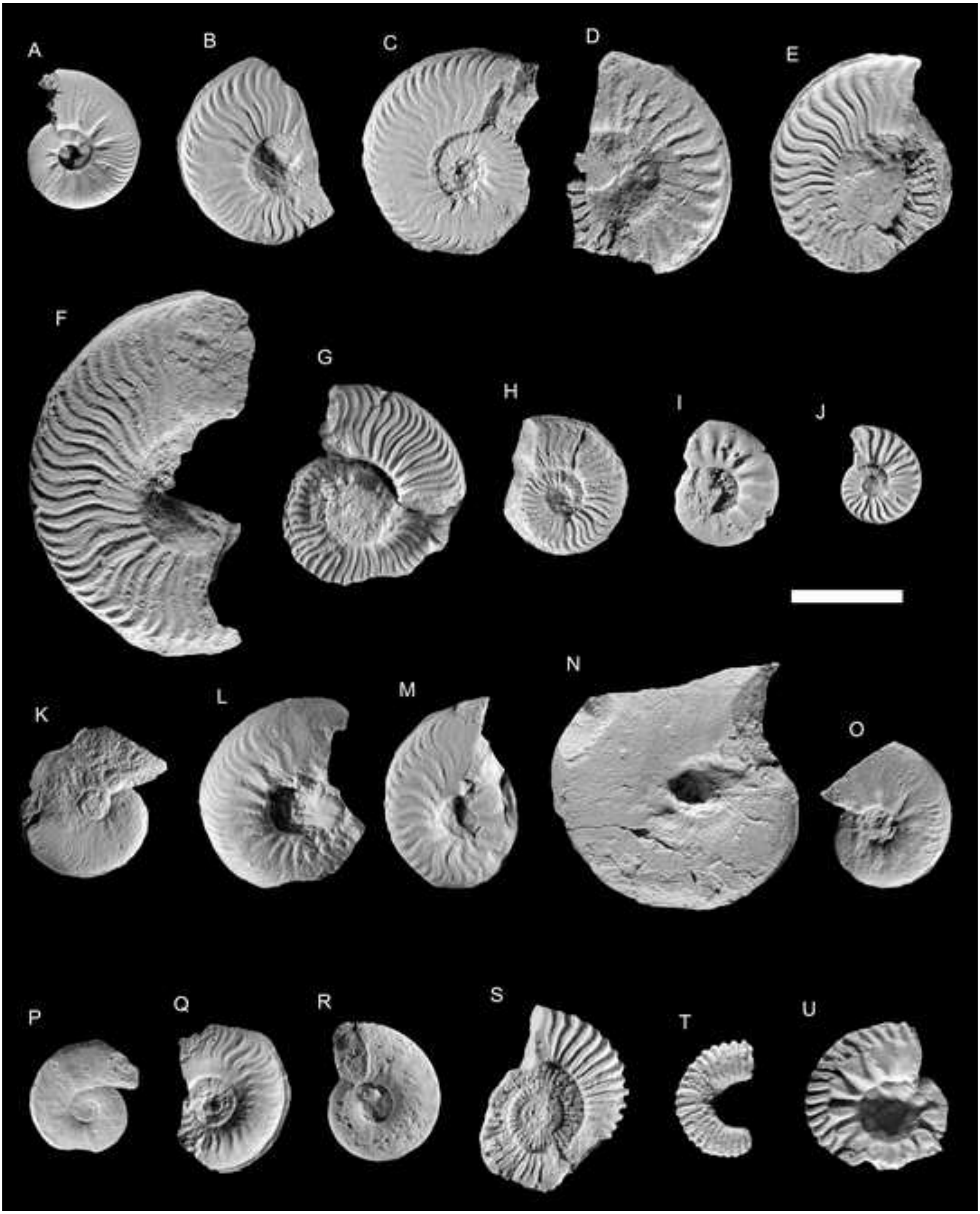

Figure 5
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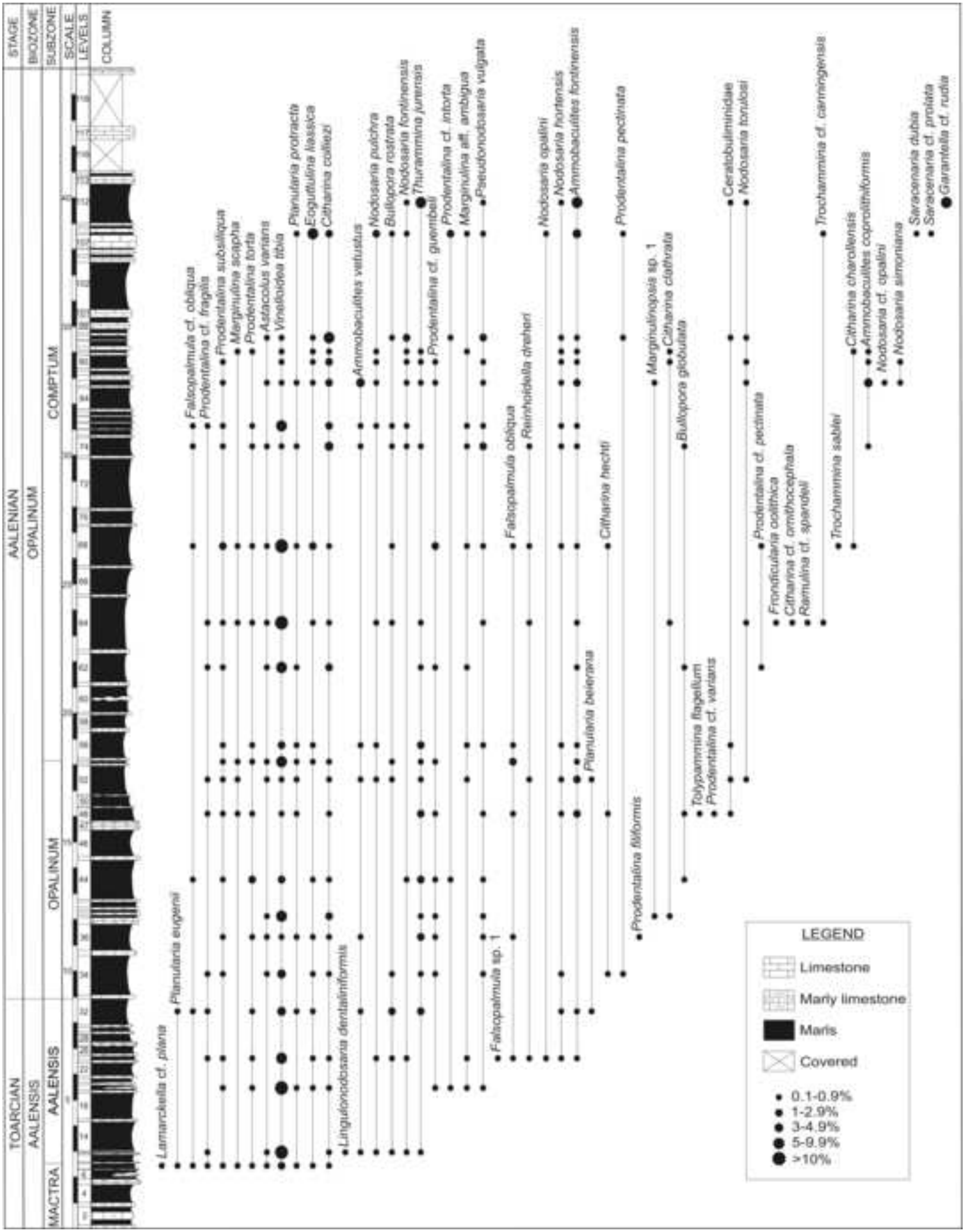

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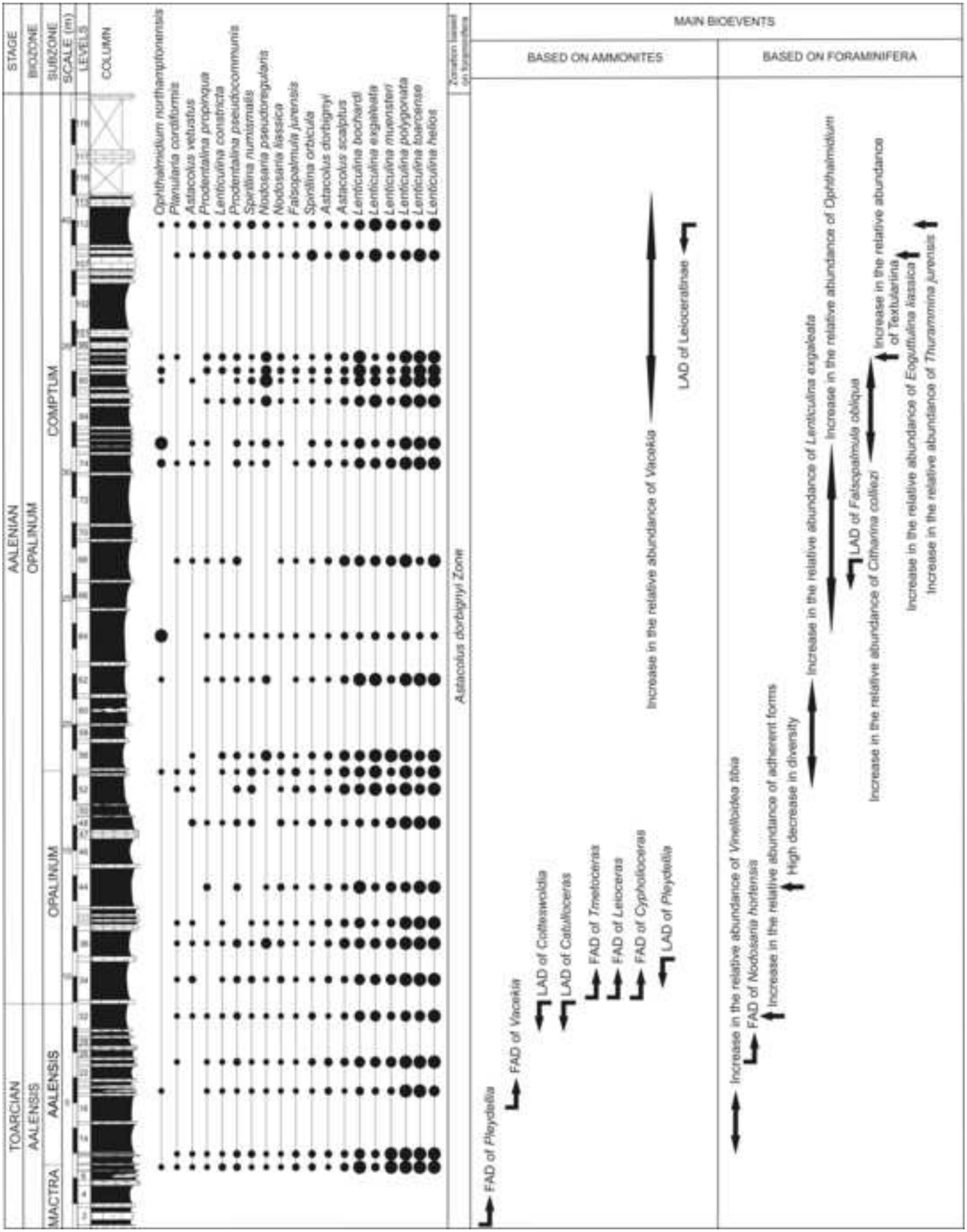

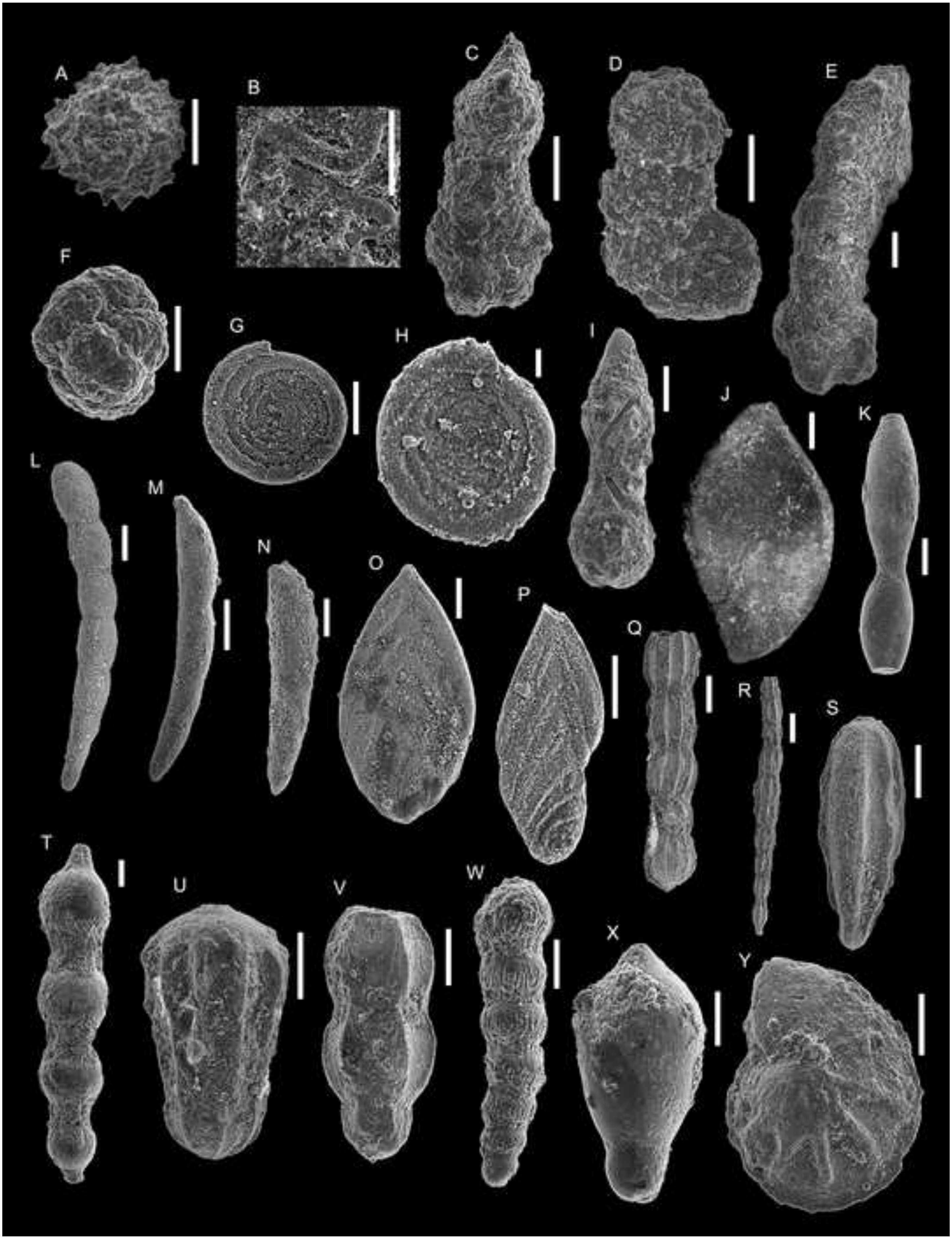
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Figure 8
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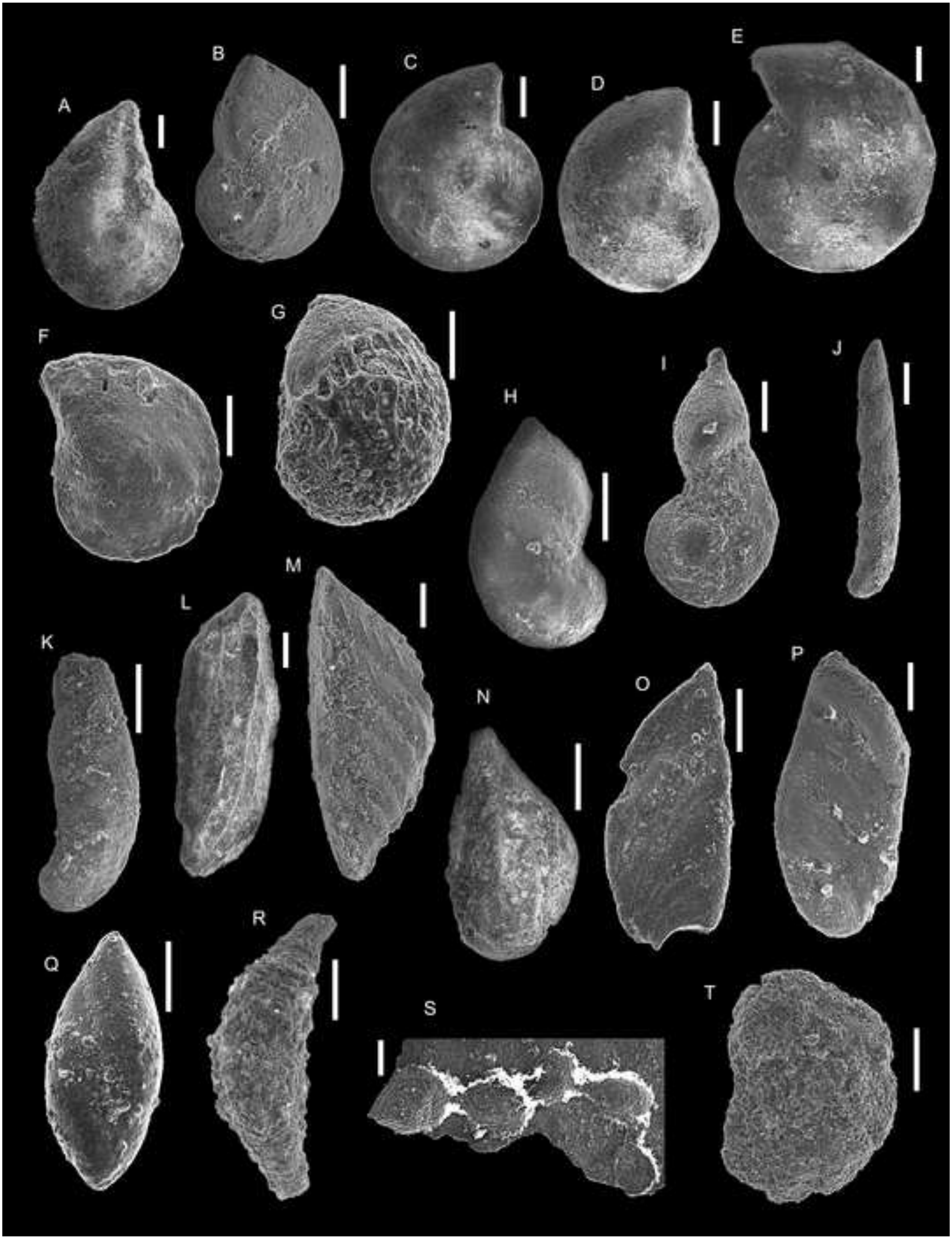

Ammonite-benthic foraminifera turnovers across the Lower-Middle Jurassic transition in the Lusitanian Basin (Portugal)

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Supplementary materials

Table S1. Number of ammonite specimens (Mactra Subzone levels).

Table S2. Number of foraminifera specimens (Mactra Subzone levels).

Table S3. Number of ammonite specimens (Aalensis Subzone levels).

Table S4. Number of foraminifera specimens (Aalensis Subzone levels).

Table S5. Number of ammonite specimens (Opalinum Subzone levels).

Table S6. Number of foraminifera specimens (Opalinum Subzone levels).

Table S7. Number of ammonite specimens (Comptum Subzone levels).

Table S8. Number of foraminifera specimens (Comptum Subzone levels).

Table S1. Number of ammonite specimens (Mactra Subzone levels).

	Level #					
Taxon	SG1	SG2	SG3	SG5	SG6	SG7
Cotteswoldia sp.	1					
C. costulata		2				
C. egena			2			
C. limatula			2			
Pleydellia sp.	2					
P. subcompta					1	
P. fluens		1	1	1		2
P. aalensis						
P. fluitans						
P. folleata						
P. lotharingica						
Cypholioceras sp.						
C. opaliniforme						
C. lineatum						
C. comptum						
Leioceras sp.						
L. opalinum						
L. costosum						
Vacekia sp.						
V. striata						
V. sourensis						
Catulloceras sp.				1		
Czerneyiceras sp.						
Bredyia sp.						
Tmetoceras scissum						
Total = 16	3	3	5	2	1	2

Table S2. Number of foraminifera specimens (Mactra Subzone levels).

	Level #
Taxon	SG8
Spirillina numismalis	2
Spirillina orbicula	14
Vinelloidea tibia	12
Ophthalmidium northamptonensis	1
Prodentalina cf. *fragilis*	2
Prodentalina propinqua	3
Prodentalina pseudocommunis	8
Prodentalina subsiliqua	4
Prodentalina torta	2
Prodentalina sp. indet.	7
Falsopalmula jurensis	9
Falsopalmula cf. *obliqua*	1
Nodosaria liassica	3
Nodosaria pseudoregularis	3
Lenticulina bochardi	49
Lenticulina constricta	5
Lenticulina exgaleata	17
Lenticulina helios	70
Lenticulina muensteri	48
Lenticulina polygonata	83
Lenticulina toarcense	62
Lenticulina sp. indet.	26
Astacolus dorbignyi	4
Astacolus scalptus	16
Astacolus varians	1
Astacolus vetustus	3
Marginulina scapha	1
Citharina colliezi	4
Planularia cordiformis	2
Planularia eugenii	1
Planularia protracta	2
Eoguttulina liassica	2
Lamarckella cf. *plana*	1
Foraminifera indet.	2

Table S3. Number of ammonite specimens (Aalensis Subzone levels).

	Level #											
Taxon	SG 9	SG 11	SG 13	SG 14	SG 16	SG 21	SG 22	SG 23	SG 25	SG 27	SG 28	SG 33
Cotteswoldia sp.	1			24					1	8		3
C. costulata		2	1	2	1		15					
C. egena							1					
C. limatula	1		4				1					
Pleydellia sp.									3			2
P. subcompta	1											
P. fluens	2											
P. aalensis	3	4		8	1	3	5	3	2	9	1	
P. fluitans												
P. folleata	1	3								1		1
P. lotharingica												
Cypholioceras sp.												
C. opaliniforme												
C. lineatum												
C. comptum												
Leioceras sp.												
L. opalinum												
L. costosum												
Vacekia sp.									1			
V. striata					1		5				2	2
V. sourensis										1		1
Catulloceras sp.										1	1	5
Czerneyiceras sp.												
Bredyia sp.												
Tmetoceras scissum												2
Total = 140	9	9	5	34	3	3	27	3	7	20	4	16

Table S4. Number of foraminifera specimens (Aalensis Subzone levels).

	Level #			
Taxon	SG12	SG18	SG24	SG32
Thurammina jurensis	1	0	0	5
Ammobaculites fontinensis	0	0	2	3
Ammobaculites vetustus	1	0	0	1
Textulariina sp. indet.	1	0	1	1
Spirillina numismalis	8	1	4	2
Spirillina orbicula	8	2	9	6
Vinelloidea tibia	77	175	27	20
Ophthalmidium northamptonensis	0	1	0	0
Ophthalmidium sp. indet.	0	1	0	0
Lingulonodosaria dentaliniformis	1	0	0	0
Prodentalina cf. *fragilis*	2	0	1	1
Prodentalina cf. *guembeli*	0	2	0	0
Prodentalina cf. *intorta*	0	1	0	0
Prodentalina propinqua	1	3	3	2
Prodentalina pseudocommunis	9	2	9	12
Prodentalina subsiliqua	0	2	3	0
Prodentalina torta	0	3	3	2
Prodentalina sp. indet.	0	4	3	1
Falsopalmula jurensis	7	4	3	3
Falsopalmula obliqua	0	0	1	0
Falsopalmula cf. *obliqua*	0	0	0	1
Falsopalmula sp. 1	0	0	1	0
Nodosaria fontinensis	1	0	1	0
Nodosaria hortensis	0	0	1	1
Nodosaria liassica	3	3	4	1
Nodosaria opalini	0	0	3	0
Nodosaria pseudoregularis	1	1	4	4
Nodosaria pulchra	1	0	1	0
Pseudonodosaria vulgata	0	1	0	0
Frondicularia oolithica	0	0	0	0
Lenticulina bochardi	56	21	40	28
Lenticulina constricta	3	1	1	1
Lenticulina exgaleata	26	12	23	22
Lenticulina helios	105	34	65	120
Lenticulina muensteri	73	12	27	17
Lenticulina polygonata	90	38	64	92
Lenticulina toarcense	141	117	75	27
Lenticulina sp. indet.	32	10	19	10
Astacolus dorbignyi	20	7	15	4
Astacolus scalptus	9	4	16	9
Astacolus varians	1	0	0	0
Astacolus vetustus	1	0	0	1
Marginulina aff. *ambigua*	0	1	1	0
Citharina colliezi	3	2	1	0
Planularia beierana	0	0	0	1
Planularia cordiformis	2	0	1	1
Planularia eugenii	0	0	0	1
Planularia protracta	0	3	0	1
Eoguttulina liassica	0	3	2	1
Bullopora rostrata	2	0	2	9
Reinholdella dreheri	0	0	1	0
Foraminifera indet.	0	0	1	0

Table S5. Number of ammonite specimens (Opalinum Subzone levels).

	Level #						
Taxon	SG34	SG35	SG37	SG39	SG43	SG45	SG52
Cotteswoldia sp.							
C. costulata							
C. egena							
C. limatula							
Pleydellia sp.	2	50					
P. subcompta							
P. fluens							
P. aalensis	4	2					
P. fluitans		6					
P. folleata							
P. lotharingica		10					
Cypholioceras sp.	1						
C. opaliniforme							
C. lineatum			1	2			
C. comptum							
Leioceras sp.	1	1	3	3			
L. opalinum	1		3	1			
L. costosum							
Vacekia sp.		1	11	19	9		
V. striata	2	1	3	8	1		
V. sourensis							
Catulloceras sp.							
Czerneyiceras sp.				2	1	2	2
Bredyia sp.							
Tmetoceras scissum							
Total = 153	11	71	21	35	11	2	2

Table S6. Number of foraminifera specimens (Opalinum Subzone levels).

	Level #						
Taxon	SG34	SG36	SG38	SG44	SG48	SG52	SG54
Thurammina jurensis	4	8	3	11	13	2	1
Tolypammina flagellum	0	0	0	0	1	0	0
Ammobaculites fontinensis	0	0	0	0	7	7	2
Ammobaculites vetustus	0	1	0	0	0	1	0
Textulariina sp. indet.	0	0	0	0	3	4	0
Spirillina numismalis	5	4	1	0	7	22	14
Spirillina orbicula	2	4	1	2	8	10	4
Vinelloidea tibia	20	2	50	8	3	1	26
Ophthalmidium northamptonensis	0	0	0	0	0	0	2
Ophthalmidium sp. indet	0	0	0	0	0	0	3
Prodentalina filiformis	0	1	0	0	0	0	0
Prodentalina cf. *fragilis*	2	0	0	0	2	3	0
Prodentalina cf. *guembeli*	4	4	1	3	2	0	1
Prodentalina cf. *intorta*	0	0	0	1	0	0	0
Prodentalina pectinata	1	0	0	0	0	0	0
Prodentalina propinqua	0	2	0	5	2	0	0
Prodentalina pseudocommunis	6	5	0	6	6	5	4
Prodentalina subsiliqua	1	1	0	1	1	1	1
Prodentalina torta	0	4	0	6	2	0	1
Prodentalina cf. *varians*	0	0	0	0	1	0	0
Prodentalina sp. indet.	2	3	1	10	2	0	3
Falsopalmula jurensis	3	4	3	2	4	12	17
Falsopalmula obliqua	0	1	0	0	1	0	6
Falsopalmula cf. *obliqua*	0	0	0	1	0	0	0
Nodosaria fontinensis	0	0	0	1	0	0	0
Nodosaria hortensis	3	0	0	0	3	2	0
Nodosaria liassica	5	8	2	8	5	4	6
Nodosaria pseudoregularis	3	21	3	1	0	0	4
Nodosaria pulchra	0	0	0	0	0	1	0
Nodosaria torulosi	0	0	0	0	0	1	0
Pseudonodosaria vulgata	1	1	5	3	1	0	0
Lenticulina bochardi	25	28	52	44	22	36	33
Lenticulina constricta	2	2	2	0	4	0	2
Lenticulina exgaleata	24	24	15	17	20	72	47
Lenticulina helios	97	91	82	60	112	91	75
Lenticulina muensteri	40	30	25	32	38	28	22
Lenticulina polygonata	94	51	68	42	69	60	48
Lenticulina toarcense	48	56	156	89	52	38	40
Lenticulina sp. indet.	35	18	47	52	33	25	31
Marginulinopsis sp. 1	0	0	1	0	0	0	0
Astacolus dorbignyi	11	9	16	10	5	5	8
Astacolus scalptus	12	23	26	6	6	35	35
Astacolus varians	1	2	2	0	0	1	3
Astacolus vetustus	5	3	1	0	5	4	4
Marginulina aff. *ambigua*	0	0	0	0	0	1	0
Marginulina scapha	0	0	0	0	1	2	1
Citharina clathrata	0	0	1	0	0	0	0
Citharina colliezi	2	3	6	1	1	1	4
Citharina hechti	1	0	0	0	1	0	0
Planularia beierana	0	0	0	0	0	1	0
Planularia cordiformis	3	1	2	0	0	4	2
Planularia protracta	0	1	0	0	4	2	1
Eoguttulina liassica	3	3	0	3	0	0	2

Table S6 (end).

	Level #						
Taxon	SG34	SG36	SG38	SG44	SG48	SG52	SG54
Bullopora globulata	0	0	0	1	1	0	0
Bullopora rostrata	2	0	0	0	0	2	2
Ceratobuliminidae	0	0	0	0	1	1	0
Reinholdella dreheri	0	0	0	0	0	3	0
Foraminifera indet.	0	0	0	0	1	0	0

Table S7. Number of ammonite specimens (Comptum Subzone levels).

	Level #																			
Taxon	SG 55	SG 57	SG 61	SG 66	SG 67	SG 71	SG 73	SG 74	SG 75	SG 83	SG 87	SG 89	SG 91	SG 93	SG 102	SG 103	SG 107	SG 112	SG 113	SG 119
Cotteswoldia sp.																				
C. costulata																				
C. egena																				
C. limatula																				
Pleydellia sp.																				
P. subcompta																				
P. fluens																				
P. aalensis																				
P. fluitans																				
P. folleata																				
P. lotharingica																				
Cypholioceras sp.	4								1					1		1				
C. opaliniforme	3																			
C. lineatum	1					1	1					1								
C. comptum	4				1	2	1	1	1				1					1		
Leioceras sp.	2		1	9		1	1	3			1		1	1		1	2			
L. opalinum	3	1	1			2										1				
L. costosum	1					2						2				1				
Vacekia sp.	11			11	1		1		1	1	2	3	5	2		2	2		1	1
V. striata	10											1			1	1	1			3
V. sourensis	1																			
Catulloceras sp.																				
Czerneyiceras sp.																				
Bredyia sp.										2										
Tmetoceras scissum				4													3		4	
Total = 138	40	1	2	24	2	8	4	4	3	3	3	7	7	4	1	7	8	1	5	4

Table S8. Number of foraminifera specimens (Comptum Subzone levels).

	Level #											
Taxon	SG56	SG62	SG64	SG68	SG74	SG78	SG86	SG90	SG92	SG96	SG108	SG112
Thurammina jurensis	7	3	3	0	1	0	2	4	1	0	0	13
Ammobaculites coprolithiformis	0	0	0	0	1	0	27	1	3	0	0	0
Ammobaculites fontinensis	3	2	1	1	2	1	11	4	3	2	15	14
Ammobaculites vetustus	2	0	0	0	2	1	26	0	0	0	0	0
Trochammina cf. *canningensis*	0	0	1	0	0	0	0	0	0	0	1	0
Trochammina sablei	0	0	0	2	0	0	0	0	0	0	0	0
Textulariina sp. indet.	0	0	1	1	0	0	36	0	0	0	2	0
Spirillina numismalis	5	3	6	0	2	3	1	19	3	2	7	9
Spirillina orbicula	7	3	4	2	13	8	7	7	6	5	24	12
Vinelloidea tibia	8	41	510	83	5	34	4	4	1	3	0	0
Ophthalmidium northamptonensis	0	1	581	0	21	57	0	2	6	6	0	1
Ophthalmidium sp. indet.	2	0	3	0	0	0	0	0	0	0	0	0
Prodentalina cf. *fragilis*	0	2	6	0	0	2	0	0	0	0	0	0
Prodentalina cf. *guembeli*	0	2	0	13	0	0	3	1	0	0	0	0
Prodentalina cf. *intorta*	0	0	0	0	0	0	0	0	0	1	5	0
Prodentalina pectinata	0	0	0	0	0	0	0	0	0	0	4	0
Prodentalina cf. *pectinata*	0	1	0	1	0	0	0	0	0	2	0	0
Prodentalina propinqua	0	1	1	1	1	2	1	0	8	11	10	4
Prodentalina pseudocommunis	7	4	7	19	7	6	13	1	4	9	15	7
Prodentalina subsiliqua	1	2	1	13	1	1	1	1	0	0	0	0
Prodentalina torta	1	0	1	3	1	3	0	0	1	0	0	0
Prodentalina sp. indet.	1	7	10	7	2	3	3	3	0	2	7	1
Falsopalmula jurensis	5	2	13	3	3	0	3	5	7	5	6	2
Falsopalmula obliqua	1	0	0	1	0	0	0	0	0	0	0	0
Falsopalmula cf. *obliqua*	0	0	0	1	1	1	0	0	0	0	0	0
Nodosaria fontinensis	0	0	0	0	2	3	3	4	2	10	3	2
Nodosaria hortensis	3	0	0	1	2	2	1	2	1	2	0	1
Nodosaria liassica	9	0	3	3	0	2	7	2	7	13	4	1
Nodosaria opalini	0	0	0	0	0	0	0	0	0	0	1	0
Nodosaria cf. *opalini*	0	0	0	0	0	0	3	0	0	0	0	0
Nodosaria pseudoregularis	30	19	11	6	11	22	42	114	19	37	11	3
Nodosaria pulchra	2	0	2	0	0	2	7	4	2	0	6	0
Nodosaria simoniana	0	0	0	0	0	0	1	5	0	0	0	0
Nodosaria torulosi	0	0	2	0	0	0	2	1	0	1	0	2
Nodosaria sp. indet.	0	0	1	0	1	0	2	0	0	0	2	7
Pseudonodosaria vulgata	2	0	7	2	6	3	4	3	0	16	4	1
Frondicularia oolithica	0	0	2	0	0	0	0	0	0	0	0	0
Lenticulina bochardi	39	46	18	30	38	44	70	54	43	101	21	22
Lenticulina constricta	12	2	4	2	0	0	3	0	5	10	8	2
Lenticulina exgaleata	58	52	46	46	39	18	91	69	22	12	64	26
Lenticulina helios	95	78	34	64	104	64	116	136	72	85	42	35
Lenticulina muensteri	57	17	18	25	38	16	28	32	15	23	16	15
Lenticulina polygonata	65	51	47	55	98	62	86	100	35	77	29	22
Lenticulina toarcense	53	63	21	24	62	80	83	159	71	139	52	10
Lenticulina sp. indet.	35	15	10	14	18	25	30	52	3	3	12	12
Marginulinopsis sp. 1	0	0	0	0	0	0	2	0	0	0	0	0
Saracenaria dubia	0	0	0	0	0	0	0	0	0	0	1	0

Table S8 (end).

	Level #											
Taxon	SG56	SG62	SG64	SG68	SG74	SG78	SG86	SG90	SG92	SG96	SG108	SG112
Saracenaria cf. *prolata*	0	0	0	0	0	0	0	0	0	0	1	0
Astacolus dorbignyi	17	1	4	6	8	9	7	21	4	10	10	4
Astacolus scalptus	30	20	22	35	15	14	29	31	18	14	45	6
Astacolus varians	0	3	2	1	2	0	5	0	0	5	0	0
Astacolus vetustus	1	0	0	3	1	3	0	2	0	0	1	3
Astacolus sp. indet.	0	0	0	2	0	0	0	0	0	0	0	0
Marginulina aff. *ambigua*	1	1	0	1	1	1	0	0	1	0	1	0
Marginulina scapha	0	0	1	2	0	0	0	0	1	0	0	0
Citharina charollensis	0	0	0	1	0	0	0	0	1	0	0	0
Citharina clathrata	0	0	1	0	0	0	0	2	1	0	0	0
Citharina colliezi	0	5	7	1	18	6	8	15	2	36	8	0
Citharina hechti	0	0	0	1	0	0	0	0	0	0	0	0
Citharina cf. *ornithocephala*	0	0	1	0	0	0	0	0	0	0	0	0
Planularia cordiformis	0	0	0	1	3	0	0	0	0	1	3	1
Planularia protracta	1	2	0	2	1	0	1	0	0	0	1	0
Eoguttulina liassica	2	0	5	10	0	0	4	2	2	5	30	0
Ramulina cf. *spandeli*	0	0	3	0	0	0	0	0	0	0	0	0
Bullopora globulata	0	1	0	0	2	0	0	0	0	0	0	0
Bullopora rostrata	0	0	1	2	2	2	0	0	0	2	1	0
Ceratobuliminidae	1	0	0	0	0	0	0	0	0	1	0	1
Reinholdella dreheri	0	0	1	1	2	0	0	0	0	0	0	0
Garantella cf. *rudia*	0	0	0	0	0	0	0	0	0	0	0	20
Foraminifera indet.	2	0	2	1	4	0	0	0	0	0	0	1

Ammonite-benthic foraminifera ~~biostratigraphy~~ turnovers across the Lower-Middle Jurassic transition ~~of São Gião section (~~in the Lusitanian Basin~~,~~ (Portugal)

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Abstract

This paper describes and ~~characterizes~~ characterises the co-occurrence of ammonite and benthic foraminiferal assemblages across the São Gião outcrop (Central Portugal), a reference section for the Lower-Middle Jurassic boundary of the Lusitanian Basin. The upper Toarcian-lower Aalenian marls and marly-limestones ~~of~~ in this section provide a precise and detailed ammonite-based biostratigraphic zonation, with a mixed assemblage of ~~N~~northwest European and Mediterranean ~~Boreal and West Tethyan~~ faunal elements, associated ~~to~~ with benthic foraminifera assemblages with northern~~of~~ ~~North Hemisphere~~ hemisphere affinities, both correlatable with the Aalenian GSSP at the Fuentelsaz section (Iberian Cordillera, Spain). A total of ~~well preserved~~ ~~463~~ 447 well-preserved ammonite specimens and 13,116 ~~foraminifers~~ foraminifera have been studied and no evidence was detected of any taphonomic processes that ~~could~~ could have changed the original assemblages ~~has been detected~~. From ~~the~~ a biostratigraphic point of view, the ammonite record has ~~allowed~~ enabled ~~the recognition~~ 4 biostratigraphic units to be recognised (the Mactra and Aalensis ~~Subzones~~ subzones of the Aalensis Biozone in the upper Toarcian, and Opalinum and Comptum ~~Subzones~~ subzones of the Opalinum Biozone in the lower Aalenian). ~~Concerning~~ With regard to the benthic foraminifera, the taxa identified have enabled ~~allowed the recognition of~~ the *Astacolus dorbignyi* Zone and~~, as well as of~~ 11 bioevents to be identified, most of which ~~them~~ representing local biostratigraphic proxies. ~~proxies of local application~~. However, the increase in the relative abundance of *Lenticulina exgaleata* Dieni from the upper part of the Opalinum Subzone to the lower part of the Comptum Subzone indicates ~~shows~~ regional value. The constant and continuous ammonite record of ~~N~~northwest European ~~North Boreal~~ taxa, together ~~aside~~ with typical Mediterranean taxa ~~along the whole section~~ - namely Grammoceratinae – ~~–~~ throughout

the section, the high relative abundance of representatives of ~~the~~ Miliolina ~~representatives~~ - generally interpreted as ~~as typical~~ foraminifers typical of shallow waters -, and the absence of ~~typical~~ foraminiferal forms typical of cool waters, do not support the inference of cool seawaters temperatures attributed to the~~, at least for the Lusitanian Basin, the inferred cool seawater temperatures assigned to the~~ Early Aalenian, or~~as well as~~ the global character of the “Comptum cooling~~”~~ event”, at least with reference to the Lusitanian Basin.

***Keywords*:** Ammonite~~s;~~ Benthic Foraminifera~~;~~ Biostratigraphy; Lower-Middle Jurassic; Lusitanian Basin; ~~Portugal~~faunal turnovers~~.~~; “Comptum cooling event”.

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1. Introduction

Ammonites are the best fossil group for dating Jurassic marine sediments, but when these fossils are poorly preserved, scarce or almost impossible to obtain (e.g. in core samples), alternative biostratigraphic scales~~,~~ based on other fossil groups~~,~~ are needed. In recent ~~the last~~ decades, there have been some attempts ~~for the~~to establish~~ment~~ ~~of~~ biostratigraphic scales based on benthic foraminifer~~s~~a ~~have been carried out~~. The precision and validity of such scales is ~~higher~~ greater when they can be calibrated with accurate biostratigraphic charts based on ammonites, as presented in this ~~paper~~research.

~~Stratigraphic~~ The stratigraphic range of most of the Jurassic foraminiferal species is relatively wide and therefore~~, so~~ the identification of bioevents, such as first occurrences (First Appearance Datum, FAD), last occurrences (Last Appearance Datum, LAD) or noticeable changes in assemblage~~s'~~ diversity or in the relative abundance of some taxa, can be a useful biostratigraphic tool.

The aim of this work is to describe, for the first time, the detailed co-occurrence of ammonite and benthic foraminiferal assemblages across the Toarcian-Aalenian boundary at São Gião section, located in Central Portugal, and to ~~recognize~~ recognise the biostratigraphic units there represented, thus contributing towards ~~for~~ calibrating the biostratigraphic scale for the Lower-Middle Jurassic boundary ~~based~~ on the bases of different fossil groups.

The São Gião section corresponds to a classical outcrop of the Lower-Middle Jurassic boundary of the Lusitanian Basin, where previous work~~s~~ on the ammonite ~~record have been~~was carried out by Mouterde et al. (1979) and Caloo-Fortier (1985). It is~~being~~ one of the few areas in Europe where this time interval is represented by an expanded section, showing exceptional exposure conditions along very fossiliferous marly-limestones sediments ~~about~~ approximately 45 m thick~~ of very fossiliferous~~

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~~marly-limestones sediments~~, ~~and~~ displaying a continuous record of ammonite representatives. ~~Despite~~ Moreover, the relevance of ~~its~~ the Grammoceratinae content for palaeobiogeographic reconstructions of the western Tethys (Sandoval et al., 2012a), and the significant *Pleydellia* and *Leioceras* record has justified the assumption of São Gião section as a reference section for the Toarcian-Aalenian boundary in the Lusitanian Basin (Henriques, 1989, 1992, 2000a; Henriques et al., 1996; Goy et al., 2000; Sandoval et al., 2001a; Azerêdo et al., 2003).~~,~~ ~~after several previous important works where its biostratigraphic relevance based on the ammonite record have been firstly pointed out (Mouterde et al., 1979; Caloo-Fortier, 1985).~~ More recently, ~~the preliminary study of~~ other fossil groups in the section have ~~has~~ been ~~carried out in the section~~studied, namely calcareous nannofossils (Henriques and Perilli, 2000), ~~but especially~~and, in particular, ~~the~~ benthic foraminifera (Magno et al., 2008; Magno, 2010; Canales et al., 2010), all suggesting the importance of analysing the detailed vertical co-occurrence of ammonite and benthic foraminifera assemblages across the Toarcian-Aalenian boundary at the São Gião section, in order to identify major faunal changes both on macrofossil and microfossil assemblages.

The bioevents ~~recognized~~ recognised in the benthic foraminifera record, ~~here~~ accurately calibrated here using ~~with~~ biostratigraphic units based on the ammonite record, represent a proxy that can be used to determinate both the age and depositional environment assigned to core samples analysis from the Lower-Middle Jurassic boundary of the Lusitanian Basin (Canales et al., 2010). Moreover, they allow the ~~re-~~interpretation of previous data ~~regarding~~ on palaeotemperature changes established for neighbouring basins located around the Iberian Plate, for exemple in the ~~such as in its~~ southern and northern palaeomargins (O´Dogherty et al., 2006; Sandoval et al., 2008; Gómez et al., 2009), as well as in more distant regions -~~,~~ in the Boreal Realm~~,~~ - ~~like~~

such as the Hebrides Basin (Price, 2010), where close relationships between major faunal-flora turnovers and isotopic fluctuations in $\delta^{13}C$ values have been ~~recognized~~ recognised (Aguado et al., 2008; Sandoval et al., 2012b).

2. Geographic and Geological settings

The São Gião section is located in the northern sector of the Lusitanian Basin (Central Portugal), at about 5 km to the South-Southwest of Cantanhede village, near Zambujal (coordinates: 40º18’12.63’’N, 8º37’17.58’’W, altitude 100 m; Fig. 1).The section is composed of greyish marly limestones, more or less compact, in regular beds with ~~variable~~ thicknesses ranging ~~(~~from 0.10 m to 0.30 m, ~~)~~ alternating with slightly thicker greyish marls beds ~~with slightly higher thickness, and organized~~ organised in shallowing-upward units, deposited in an external marine ~~external~~ platform environment. The limestone component progressively increases towards the top of this unit, which corresponds to the upper part of the Póvoa da Lomba Formation (upper Toarcian – upper Aalenian).

The Póvoa da Lomba Formation was firstly informaly defined by Barbosa et al. (1988, 2008) as ~~an informal~~a lithostratigraphic unit named the "Calcários Margosos de Póvoa da Lomba” (“Póvoa da Lomba Marly Limestones”), and later ~~formalized~~ formalised as the Póvoa da Lomba Formation by Azerêdo et al. (2003). It corresponds laterally to the lower part of the Cabo Mondego Formation which outcrops at the west of the basin, ~~to~~ the upper part of the Prado Formation outcropping eastwards, and ~~to~~ the top of the Fórnea Formation - base of the Barranco de Zambujal Formation which outcrops ~~at~~ in the southeast of the basin (Azerêdo et al., 2003; Fig. 2).

3. Material and Methods

~~For the~~In order to study ~~of~~ the ammonite record, 44 successive bed-by-bed samplings were obtained from~~has been carried out along~~ 36 marly-limestones beds and 8 marly beds. A total ~~amount~~ of 447 ammonite specimens ~~have been~~were collected and identified according to the systematic classification proposed by Henriques (1992).

A total of 24 marly beds were sampled ~~F~~for the study of the benthic foraminiferal assemblages ~~a total of 24 marly beds were sampled~~ along the ~~studied~~ stratigraphic interval studied, taking the thickness of each ammonite subzone into account ~~the thickness of each ammonite subzone~~. 300 g of each sample ~~was~~were processed in the laboratory ~~following~~using a classical methodology ~~that consists in~~involving a mixture of sodium hydroxide, hydrogen peroxide and water ~~during~~for 2-3 days. ~~After this time~~Following this, the samples were washed over a column ~~of mesh sieves~~ of 1 mm, 0.500 mm, 0.250 mm, 0.125 mm and 0.060 mm mesh sieves. ~~D~~The dry residues were weighed and subsequently picked to obtain the foraminifer~~s~~a, using ~~a~~ Wild M-8 binocular magnifying glasses. The ~~classification of the~~ specimens recovered were classified ~~specimens~~, at suprageneric and generic rank, ~~followed~~using the Loeblich and Tappan (1988) systematic; and the Ellis and Messina (1940-1990) foraminifera catalogue was consulted for the specific rank classification. The photographs of the figured specimens were taken at the Centro Nacional de Microscopía Electrónica, ~~located in~~at the Universidad Complutense de Madrid (Spain) using a~~n~~ JEOL-JSM 6400 electronic microscope ~~model JEOL JSM 6400~~.

~~In both fossil groups,~~The species richness and relative abundances ~~have been~~were calculated for both fossil groups. Species richness is understood as the number of species (or other taxonomical category) in a sampling unit, in ~~respect of~~relation to the total number of identified species (or other taxa). Relative abundances ~~are~~is expressed as a percentage, in relation to the total number of specimens obtained in each assemblage.

All the material ~~-~~– the ammonites and foraminifera specimens (including the residues of the samples studied~~-samples~~) - is stored ~~at~~in the Laboratório de Geologia Sedimentar e Registo Fóssil, ~~located in~~at the Departamento de Ciências da Terra, Faculdade de Ciências e Tecnologia at the~~,~~ Universi~~dade~~ty of ~~de~~ Coimbra (Portugal).

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4. Taphonomic considerations

The preservational features of ~~Taphonomic analysis of~~ the ammonite assemblages can be ~~characterized~~ characterised according to several taphonomic parameters described for ~~the~~ *Tmetoceras* from the Iberia (Fernández López et al., 1999a,b) and for other ammonites from the Lower Pliensbachian of Portugal (Fernández López et al., 2000). Marly limestones mainly record ~~mainly~~ resedimented elements, whereas accumulated shells are virtually absent and re-elaborated elements are scarce. Ammonite assemblages are composed of incomplete phragmocones normally filled with sediment and, in general, ~~they generally~~ appear scattered in the sediment, showing no pattern of imbricate or encased grouping. Complete shells are scarce and pyritic internal moulds are only found ~~only~~ locally and assigned to marly levels. The degree of ammonite packing – estimated by the difference between the number of specimens and the number of fossiliferous levels divided by the number of fossiliferous levels -, and the ammonite stratigraphical persistence - i.e., the proportion of fossiliferous levels - ~~display~~ presents high values (9.15 and 38%, respectivelly), whereas the degree of taphonomic heritage - i.e., the ratio of re~~-~~-elaborated elements ~~to the~~as a whole ~~of recorded elements~~ - is very low or even 0%.

The ratio between the amount of preserved elements and the amount of species ~~display~~ reveals high values (26.3);~~,~~ specific diversity, i.e., the inverse ratio, is relatively low (0.04), and adult shells are scarce. ~~Such~~ These taphonomic features, by disproving sorting processes ~~of sorting by~~involving mechanical transport, ~~allow~~ supporting the demic ~~character~~ nature of the fossil assemblages, as pointed out by Fernández López and Meléndez (1995) for the Phylloceratina and by Fernández López et al. (1999b) for the *Tmetoceras* of the Iberian basins during the Middle Jurassic.

Concerning the benthic foraminifera record, most of the 13.~~,~~116 specimens recovered ~~show a~~ are very ~~good preservation~~well preserved. From a taphonomic point of view, only breakages, sedimentary infillings of the chambers, dissolution (partial or even total, as is the case of some representatives of the Family Ceratobuliminidae), distortion and ~~recrystallization~~ recrystallisation (Herrero and Canales, 2002) ~~have been~~were observed in some specimens, but no evidence of any alteration ~~of~~ to the ~~studied~~ assemblages can be inferred. The two ~~last~~ latter studied samples come from harder sediments and, as a consequence, the surface of the specimen~~'~~s ~~surface~~ appeared to be ~~frequently~~ covered by calcite crusts, thus hindering their taxonomic identification at specific rank.

~~4~~5. Results

The co-occurrence of ammonite and benthic foraminiferal assemblages across the São Gião outcrop provides a precise and detailed ammonite-based biostratigraphic zonation as well as an alternative biostratigraphic scale~~,~~ based on benthic foraminifera. In addition, the identification of bioevents, such as first occurrences (First Appearance

Datum, FAD), last occurrences (Last Appearence Datum, LAD) or noticeable changes in assemblages' ~~diversity~~ species richness or in the relative abundance of some taxa ~~of~~ in both fossil groups, ~~can~~ may prove to be a useful biostratigraphical proxy.~~, as~~ S~~s~~uch bioevents are, ~~for the moment~~so far, ~~initially~~ considered to be of local application. It is expected that future analyses in the same basin or in other basins~~,~~ will allow for correlations between different sections, based on some of these bioevents~~,~~. ~~but future analyses carried out in other areas, inside the same basin or in other basins, will allow the recognition of bioevents of regional usefulness and, consequently, the establishment of correlations between different sections~~. Moreover, the taxonomic composition of the assemblages and the ~~recognized~~ recognised bioevents ~~at~~ in the São Gião section provide relevant palaeoecological data for ongoing discussions on the relationships between major faunal turnovers and palaeotemperature changes during the Early Jurassic-Middle Jurassic transition.

5. ~~4.~~1. Ammonite and benthic foraminiferal assemblages

The ammonite record of São Gião section mainly includes ~~mainly~~ some typical ~~Boreal~~ ~~n~~northwest European Grammoceratinae (*Catulloceras*, *Cotteswoldia*, *Pleydellia*) in the upper Toarcian, and Leioceratinae (*Leioceras*, *Cypholioceras*) in the lower Aalenian, ~~aside~~ together with typical Mediterranean Grammoceratinae (*Vacekia*), Tmetoceratinae (*Tmetoceras*) and ~~scarce~~ rare Hammatoceratidae (*Bredya* and *Czerneyiceras*) (Fig. 3). No typically Tethysian phylloceratids ~~have been~~were found among the ~~32~~ 20 species (some of ~~them~~ which are represented in Fig. 4) ~~corresponding to 20~~ 9 ~~genera which have been identified~~.

~~Foraminiferal~~ The foraminiferal assemblages recorded along the ~~studied~~ stratigraphic interval studied are very abundant and ~~diverse~~ display a high species richness (Figs. 5

and 6). ~~Thus, a~~A total of 71 species (some of ~~them~~ which are represented in Figs. 7 and 8), corresponding to 26 genera and 5 suborders, have been identified, all typical ~~of them typical~~ of the Jurassic platforms ~~of~~ in the ~~North~~ northern ~~Hemisphere~~hemisphere.

~~54~~5.1.1. Aalensis Biozone, Mactra Subzone (SG1-SG8; 3.5 m ~~of greyish marls~~ of 0.70 m thick greyish marls alternat~~ing~~e with 0.15 m thick lenticular greyish marly limestones ~~of 0.15 m thick, displaying~~with abundant ammonite content).

Index fossil: *Pleydellia mactra* (Dumortier).

The ammonite assemblage ~~recognized~~ recognised in this ~~Subzone~~subzone, which corresponds to 6 fossiliferous levels, ~~shows~~ reveals low ~~abundance~~ number of specimens (16 ~~specimens~~) but a relatively high number of species ~~and diversity~~ (5 identified species corresponding to~~;~~ 2 ~~identified~~ genera). Most ~~of them~~samples correspond to the ~~genus~~ *Cotteswoldia* genus, namely ~~to~~ the ~~species,~~ *C. limatula* Buckman ~~(2 specimens)~~, *C. egena* Buckman ~~(2)~~ and *C. costulata* (Zieten) ~~(2)~~ species (representing 38% of the identified species), and ~~to~~ the ~~genus~~ *Pleydellia* genus, namely ~~to~~ the ~~species~~ *P. fluens* ~~(5 specimens~~ (Buckman)~~)~~ and *P. subcompta* Branco species (representing 38% of the identified species) (table S1)~~,~~. The ~~the last one being~~ latter ~~-~~is a significant component of the recorded assemblages, as it represents earlier *Pleydellia*, thus ~~characterizing~~ characterising the subzone, whose base is ~~recognized~~ recognised by the FAD of ~~those~~ these forms.

The only foraminiferal assemblage studied from the Mactra Subzone (Aalensis Biozone, Upper Toarcian) corresponds to sample SG-8. A total of 469 specimens were obtained, ~~from which~~ 434 (93%) of which were identified at specific level. ~~Having~~ Taking into account the number of grams of picked sediment, in this sample the abundance ~~attaints~~ amounts to 60.5 foraminifera per gram of sediment picked. In this assemblage, 4

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suborders (Spirillinina, Miliolina, Lagenina and Robertinina) were identified, ~~being~~ in which Lagenina was the most abundant (~~with 404 specimens~~ representing 87%) ~~the most abundant~~. Spirillinina and Miliolina ~~show~~ occur in percentages ~~below~~ of less than 4% and Robertinina~~, with only one~~(1 specimen)~~,~~ ~~and~~ can be considered a minority. ~~It is remarkable t~~The total absence, in this assemblage, of ~~the~~ representatives of the ~~Suborder~~ Textulariina Suborder is notable, ~~which~~ given that these are present, even if in small numbers, in Lower-Middle Jurassic foraminiferal assemblages of other coeval basins (Canales and Herrero, 1996, 2000; Canales and Ureta, 1997; Canales, 2001; Canales and Heriques, 2007, 2008; Figueiredo, 2009; Canales et al., 2010; Figueiredo et al., 2010; Guterres, 2010; Magno, 2010; Figueiredo and Guterres, 2012). At ~~the~~ generic level, a total of 13 genera were identified, ~~where~~ in which *Lenticulina*, with ~~359 specimens, that represent~~ a relative abundance of 77%, ~~shows a~~ clearly ~~dominance~~ predominates~~over the others~~. ~~At the~~On a specific level, a total of 31 species were identified, ~~being~~ of which *Lenticulina polygonata* (Franke) was the most abundant.~~,~~ ~~with 83 specimens that represent a relative abundance of~~ (19%)~~.~~ ~~No dominance~~There was no evidence of any single ~~of any~~ species dominating over the others ~~has being detected~~ (Table S2).

~~5~~45.1.2. *Aalensis Biozone, Aalensis Subzone* (SG9-SG33; 7.5 m of greyish marls ~~of variable~~with thicknesses varying~~,~~ ~~between~~ from 0.15 and 1.10 m, ~~alternate~~ alternating with 0.15 m thick of bioturbated greyish marly limestones ~~0.15m thick~~, displaying very abundant, sometimes ~~pyritized~~pyritised, ammonite internal moulds).

Other biostratigraphic units have been proposed for the upper part of the Aalensis Biozone. Page (2003) uses *P. fluitans* as index for the Fluitans Subzone. However, *P. fluitans* has a scarce record in the Lusitanian Basin and, as pointed by Elmi et al. (1997,

p. 34), "sa position stratigraphique au sein de la zone à Aalensis ne nous paraît pas bien établie, ce qui justifie son abandone en tant qu´indice". Concerning the Lugdunensis Subzone, it has been established due to traditional misinterpretations of *P. aalensis* (Z~~IETEN~~ieten) by some authors. According to Elmi et al. (1997, p. 34), "L´école française utilisait une sous-zone à Aalensis pour cet interval de temps [Sous-zone à Lugdunensis] en faisant référence à l´espèce figurée par~~a~~ D~~UMORTIER~~umortier (1874, Pl. L, fig. 1-3) qui est bien différente du type de Zieten (…) Afin d´éviter de pérenniser les confusions, nous proposons le nouveau nom de *Pleydellia (Walkericeras) lugdunensis* (…)" for the French forms of *Walkericeras*, previously interpreted as *P. aalensis* sensu Dumortier non Zieten, the original author of the *aalensis* species. But the Aalensis Biozone, based on the occurrence of its index fossil - *P. aalensis* (Z~~IETEN~~ieten), i.e., specimens displaying rounded umbilical wall and variable ribbing during ontogeny, according to the original interpretation by Zieten (1830) - is perfectly recognizable in several basins around the Iberian Plate, where correlation has been already established (see, for instance, Goy et al., 2000), namely at Fuentelsaz (the Aalenian GSSP).

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Index fossil: *Pleydellia aalensis* (Zieten).

The ammonite assemblage ~~recognized~~ recognised in this subzone, which corresponds to 1~~1~~2 fossiliferous levels, ~~shows~~ reveals high abundance (140~~37~~ specimens; 118~~85~~ of which were identified at species level) and high number of taxa ~~low~~ high ~~diversity~~ (10 identified species; 4 identified genera). The base of the subzone is defined by the FAD of the index species – i.e., *P. aalensis* (Zieten, 1830 non Dumortier, 1874) ~~species representatives (32 specimens)~~, which dominate amongst the fauna (39 specimens representing 33~~8~~% of the identified species), in association with *P. folleata* (Buckman).

The base of the subzone also records the ~~(6 specimens) and~~ last occurrence of *P. subcompta* Branco ~~(1 specimen)~~ and *P. fluens* (Buckman). ~~(2 specimens) on its base.~~ *Cotteswoldia costulata* (Zieten) (~~21 specimens and 25~~18% of the total identified species), *C. limatula* Buckman ~~(6 specimens)~~ and *C. egena* Buckman ~~(1 specimen)~~ representatives, which occurred ~~occurring~~ in the ~~later~~ previous subzone, still remain ~~remain~~ ~~persist~~ here. Last *Catulloceras* occur together with the first *Tmetoceras*; *Vacekia sourensis* (Perrot) ~~(2 specimens; 12% of the identified species)~~ and early striate *Vacekia*, like *V. striata* Henriques (Sandoval et al., 2012a) ~~(10 specimens)~~, are also relatively abundant (10% of the identified species).~~.~~ ~~Marly~~ The marly levels of the thick SG 14 bed ~~SG 14 display~~ reveal a great~~high~~ abundance of ~~pyritized~~ indeterminate pyritised ~~nucleus of indeterminate~~ *Cotteswoldia* ~~(24 specimens)~~ and *Pleydellia* nucleus ~~(8 specimens)~~ (Table S3).

Four foraminiferal assemblages (SG-12, SG-18, SG-24 and SG-32) ~~From~~ from the Aalensis Subzone (Aalensis Biozone, Upper Toarcian) ~~4 foraminiferal assemblages (SG-12, SG-18, SG-24 and SG-32) have been~~were studied. A total of 2.~~,~~006 specimens were recovered, 1.922 of which ~~1,922, representing 96%,~~ were classified ~~to~~ on a specific ~~rank~~level. The average abundance in these assemblages ~~attaints~~ amounts to 94 foraminifera per gram of picked sediment. At ~~the~~ suborder ~~rank~~level, representatives of Textulariina, Spirillinina, Miliolina, Lagenina and Robertinina were identified, ~~being~~ within which Lagenina was the most abundant (~~with a relative abundance of~~ 82%~~,~~ of the assemblage), followed by Miliolina, with a relative abundance of 15%. This fact is remarkable, since as representatives of this suborder, ~~when~~ if present in Toarcian-Aalenian foraminiferal assemblages, are usually very ~~scarce~~ rare (Herrero and Canales, 1997; Canales and Herrero, 2000; Canales, 2001; Henriques and Canales, 2007, 2008; Figueiredo, 2009; Figueiredo et al., 2010; Figueiredo and Guterres, 2012). ~~.~~The remaining suborders can be considered minority in terms of these assemblages, with relative abundances of less than 2%. At ~~the~~ generic level, 18 genera were identified in these assemblages ~~18 genera have being identified~~ and, again, the representatives of the genus *Lenticulina*, ~~with 1,392 specimens,~~ representing ~~a relative abundance of~~ 69% of the assemblage, ~~are~~ were dominant ~~over the others~~. Moreover, the large amount ~~it is noticeable the high number~~ of representatives corresponding to the genus *Vinelloidea* (Miliolina Suborder), whose relative abundance ~~attaints~~ amounts to 15%, is noticeable. A ~~high~~ great number of species (~~, namely ,~~ 45 in total), have been identified in these assemblages. Among them, *Lenticulina toarcense* Payard is the most abundant~~,~~ (~~with a relative abundance of~~ 18~~18~~% of the assemblage), but no single species was markedly dominant ~~dominance of any species has been noticed~~ (Table S4).

~~5~~45.1.3. Opalinum Biozone, Opalinum Subzone (SG 34~~3~~-SG 54; 8 m of ~~alternations~~ alternating ~~of~~ greyish marly limestones in ~~beds of~~ 1 m thick beds, and thin micritic marly limestones in 0.20 m thick beds ~~of 0.20m thick~~, including very abundant, sometimes ~~pyritized~~pyritised, ammonite internal moulds).

Index fossil: *Leioceras opalinum* (Reinecke).

The assemblage recognis~~z~~ed in this subzone corresponds to 7 fossiliferous levels, displaying the greatest ~~which shows the highest~~ abundance and ~~diversity~~species richness in the whole section (153 specimens; 45 identified at species level; 6 identified species; 5 identified genera)~~highest abundance (171 specimens; 51 identified at species level) and diversity (9 identified species; 8 identified genera) in the whole section~~. The base of the subzone is ~~characterized~~ characterised by the FAD ~~of~~ for *Leioceras opalinum* (Reinecke), which appears in association with *Pleydellia* representatives until bed SG 35, where the LAD ~~of~~ for this taxon is recorded (Fig. 3). *P. aalensis* (Zieten), *P. folleata* (Buckman), *P. lotharingica* (Buckman) and *P. fluitans* (Dumortier) co-exist at the base with the first Leioceratinae, representing 48~~6~~% of the total recorded assemblages ~~of~~ ~~the~~in this subzone, followed by *Vacekia* representatives, mainly *V. striata* Henriques, which ~~attain~~ total 10~~34~~%. *Cypholioceras lineatum* (Buckman), *Leioceras opalinum* (Reinecke) and indeterminate species of both genera represent only about 11~~0~~% of the total recorded ammonites. ~~Scarce~~Rare *Czerneyiceras* also feature in ~~characterize~~ the ammonite assemblages of this unit~~Scarce *Tmetoceras scissum* (Benecke) and *Czerneyiceras* also characterize the ammonite assemblages of this unit~~, ~~where~~ in which the LAD of several taxa have been ~~recognized~~ identified – namely *Pleydellia*, *Cotteswoldia* and *Catulloceras* – ~~aside~~ together with the FAD of others – *Cypholioceras*, *Leioceras* and~~,~~ *Czernyeiceras* ~~and *Tmetoceras*~~ – corresponding to an important ammonite turnover from the typical Late Toarcian taxa ~~towards~~ to the characteristic Early Aalenian taxa. ~~Such~~This turnover,~~,~~ which can be accurately assigned to Opalinum Subzone, is particularly well documented ~~in bed~~by the SG 35 assemblage ~~of~~ in the São Gião section (Table S5).

Seven foraminiferal assemblages ~~From~~ from the Opalinum Subzone, ~~7 foraminiferal assemblages,~~ corresponding to samples SG-34, SG-36, SG-38, SG-44, SG-48, SG-52 and SG-54, were ~~have been~~ studied. A total of 3.~~,~~285 specimens were recovered, 3.012 of which ~~3,012 representing 92%~~ have been classified ~~to~~ within a specific level. The average abundance in these assemblages ~~attaints~~ totals 74 foraminifera per gram of sediment picked. As in the ~~precedent~~ previous subzone, 5 suborders ~~have been~~were identified, namely Textulariina, Spirillinina, Miliolina, Lagenina and Robertinina~~,~~ and, again, Lagenina is the dominant ~~one~~suborder, with a relative abundance of 91%, followed by Miliolina~~, which shows a relative abundance of~~ (4%), and Spirillinina~~, with a relative abundance of~~ (3%). The~~Suborders~~ Textulariina and Robertinina suborders are very ~~scarce~~ rare (<~~, showing both relative abundances of less than~~ 2%). At ~~a~~ generic level, a total of 19 genera ~~have been~~were ~~recognized~~identified, within which~~. Among them, the dominance of the~~ representatives of ~~the genus~~ *Lenticulina* genus~~,~~ (~~with a relative abundance of 74%), continues~~continued to predominate. Within the ~~whole~~ unit, a total of 53 species ~~have been~~were identified, ~~a number that overcomes the one~~which exceeds the number obtained for the Aalensis Subzone. ~~No~~ There is no evidence for the

Formatted: Right: -0.04 cm, Space Before: 1.45 pt, Line spacing: 1.5 lines, No widow/orphan control, Don't adjust space between Latin and Asian text, Don't adjust space between Asian text and numbers dominance of any single species, although ~~has been detected, but~~ the most abundant ~~of all of them~~ is *Lenticulina helios* (Terquem), with a relative abundance of 19% (Table S6).

~~54~~5.1.4. *Opalinum Biozone, Comptum Subzone* (SG 55-SG 119; 28 m thick of greyish marls of irregular thickness ranging from 0.20 to 2 m, ~~alternations~~ alternating ~~of greyish marls of irregular thickness, ranging from 0.20 to 2m thick, and~~with limestones, which are marly and grey ~~in colour~~ at the base, ~~but~~ becoming ~~more and more~~ whiter and more micritic towards the top of the succession).

Index fossil: *Cypholioceras comptum* (Reinecke).

The assemblage ~~recognized~~ recognised in this subzone, which corresponds to 20 fossiliferous levels, ~~shows~~ reveals relatively high number of specimens (138 specimens; 70 identified at species level) and high number of taxa ~~abundance (1389 specimens; 7063 identified at species level) and diversity~~ (8 identified species belonging to 4 different genera and 2 indeterminate species, one of *Bredyia* and another of *Czernyeiceras*). The base of the subzone is defined by the FAD of the fossil index representatives, associated to other species of the genus *Cypholioceras* - *C. opaliniforme* (Buckman), *C. lineatum* (Buckman) representing 27% of the total species identified ~~species~~ -, and ~~to~~ forms of *Leioceras* (ranging from the striated *L. opalinum* (Reinecke) to the costulated *L. costosum* (Quenstedt), which represent 20~~5~~% of the total material identified ~~material~~). All Leioceratinae disappear at SG 107, where the facies abruptly change to micritic white limestones. *Vacekia striata* Henriques and *V. sourensis* (Perrot), as well as *Tmetoceras scissum* (Benecke) ~~representatives~~ persist within this subzone, the ~~first ones~~ former being ~~dominant rather important~~quite significant (26~~30~~% of the identified species) within the unit as a whole ~~unit~~, and particularly when Leioceratinae ~~reduce their~~is less ~~abundance~~ abundant or absent ~~and/or lacks~~ (Table S7).

~~Having into account the high~~Taking the significant development of the Comptum Subzone in the São Gião section into account, 12 foraminiferal assemblages, corresponding to samples SG-56, SG-62, SG-64, SG-68, SG-74, SG-78, SG-86, SG-90, SG-92, SG-96, SG-108 and SG.112, were studied. A total of 7.~~,~~363 specimens were recovered, 7.071of which ~~7,071, that represent 96% of the total, w~~ were identified at ~~the~~ specific level. Again, specimens corresponding to the suborders Textulariina, Spirillinina, Miliolina, Lagenina and Robertinina were obtained, with the Lagenina Suborder domina~~nce~~ting (76%). ~~being the representatives of the Suborder Lagenina, with a relative abundance of (76%), the most frequent. As in the Aalensis Subzone, t~~The representatives of the Miliolina Suborder ~~Miliolina~~ show a relative abundance of 19%. Again, the representatives of this suborder are more frequent than in coeval Upper Toarcian-Lower Aalenian ~~iberian~~ Iberian sections (Herrero and Canales, 1997; Canales and Herrero, 2000; Canales, 2001; Henriques and Canales, 2007, 2008; Figueiredo, 2009; Figueiredo et al., 2010; Figueiredo and Guterres, 2012). In these assemblages, the representatives of the remaining suborders are ~~scarce~~ rare and all ~~of them show~~display relative abundances of less than 3%, ~~and~~ or even less than 1%, ~~as is~~in the case of Robertinina. At ~~the~~ generic level, a total of 24 genera ~~have been~~were identified, ~~also~~ with the representatives of the genus *Lenticulina* again presenting~~, with 4,115 specimens, showing~~ the ~~higher~~ highest relative abundance (56%)~~, but not a clear dominancebeing dominant~~and dominating over the remaining genera. ~~IThus, it is remarkable t~~The relative abundance of other genera such as ~~attained by other genera as~~ *Vinelloidea* (9%), *Ophthalmidium* (9%), *Nodosaria* (6%), *Astacolus* (6%), *Prodentalina* (4%) and *Ammobaculites* (2%) is also notable, ~~because~~ since they ~~are much more~~

~~scarce~~were much rarer in ~~the precedent~~previously studied assemblages. Finally, at ~~the~~ specific level, a total of 63 species ~~have been~~were ~~recognized~~identified ~~within the whole unit~~, ~~being~~ of which *Lenticulina helios* (Terquem)~~, with 925 specimens representing a relative abundance of 13%,~~) is the most abundant ~~one~~(13%) (Table S8).

5.2. *Biostratigraphic significance of the recorded assemblages*

The ammonite record (447~~63~~ specimens, 20~~32~~ species, 9~~20~~ genera) ~~of~~ for the São Gião section has ~~allowed~~ enabled 4 biostratigraphic units ~~the~~ to be ~~recognition~~ recognised ~~of 4 biostratigraphic units~~ (Mactra and Aalensis ~~Subzones~~ subzones of the Aalensis Biozone in the U~~u~~pper Toarcian, and Opalinum and Comptum ~~Subzones~~ subzones of the Opalinum Biozone in the L~~l~~ower Aalenian; Fig. 3). This biostratigrahic zonal scheme has been ~~recognized~~ recognised in the Lusitanian Basin, as well as in other coeval basins of the Iberian Peninsula (Henriques, 1995; Henriques et al., 1996; Sandoval et al., 2001a) namely at Fuentelsaz section (Iberian Cordillera), where the Aalenian GSSP has been established (Cresta et al., 2001).

From a biostratigraphic point of view, based on benthic foraminifera, the taxa identified in São Gião (13.~~,~~116 specimens, 71 species, 26 genera, 5 suborders) have allowed for the recognition of the *Astacolus dorbignyi* Zone - in the sense of the Dorbignyi Zone proposed by Canales (2001) in the Basque-Cantabrian Basin (Northern Spain) for the Lower-Middle Jurassic transition ~~-~~, ~~being~~ with *Astacolus dorbignyi* (Roemer) ~~its~~ serving as the index fossil (Fig. 6). This zone has also been ~~recognized~~ recognised in other sections of the Lusitanian Basin (Figueiredo, 2009; Guterres, 2010; Magno, 2010; Canales et al., 2010; Figueiredo et al., 2010; Figueiredo and Guterres, 2012). Its lower boundary is marked by the first record of the index species, ~~not~~ previously ~~recognized~~ unrecognised ~~until now~~ in the Lusitanian Basin, ~~and its~~whose upper boundary coincides

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with the first record of *Lenticulina quenstedti* (Gümbel), the index species ~~of~~ for the *Lenticulina quenstedti* Zone, which has been ~~characterized~~ characterised as belonging to ~~from~~ the upper part of the Gigantea Subzone (Bradfordensis Biozone, Middle Aalenian) at the Bajocian GSSP in Murtinheira section (Portugal) (Canales and Henriques, 2013~~2~~).

6~~5~~. Discussion

The composition of the ammonite assemblages in the São Gião section ~~displays a~~is cosmopolitan ~~character~~in nature, with a constant and continuous record of both ~~the~~ ~~Northwest~~ northwest ~~Boreal~~ European taxa - thus allowing the recognition of the standard biozonation established for the Lower-Middle Jurassic transition-, ~~aside~~ together with typical Mediterranean taxa - thus increasing its correlation potential with sections located in both ~~domains~~provinces. ~~They~~ Both reproduce the general trends already ~~recognized~~ recognised in other coeval sections of the Lusitanian Basin and of the Iberian Plate (Henriques, 1989, 1992, 1995, 2000a,b; Henriques et al., 1996; Goy et al., 2000; Sandoval et al., 2001a; Azerêdo et al., 2003), ~~but~~ although the ammonite content displays some peculiarities of stratigraphic and palaeoecological relevance, as described in 6.1. and 6.3.

The general composition of the foraminiferal assemblages recorded in São Gião is also comparable with other coeval sections, not only in the Lusitanian Basin (Canales and Henriques, 2007, 2008; Figueiredo, 2009; Figueiredo et al., 2010; Guterres, 2010; Magno, 2010; Figueiredo and Guterres, 2012), but also in other Iberian sections (Canales and Herrero, 1996, 2000; Canales and Ureta, 1997; Herrero and Canales, 1997; Canales et al., 2000; Canales, 2001). However, like the ammonite fauna, the foraminiferal assemblages display some peculiarities ~~related to~~in terms of their ~~diversity~~species richness and ~~to~~ the main components of the assemblages, ~~also~~which are of stratigraphic and palaeoecological relevance, as described in 6.1. and 6.3.

~~.~~

6.1. Ammonite record and stratigraphic implications

~~Concerning~~ With regard to the stratigraphic range of the index species *Pleydellia aalensis* (Zieten) and *Leioceras opalinum* (Reinecke), their co-existence at the base of the Opalinum Subzone has been clearly confirmed, corresponding to a bioevent ~~recognizable~~ recognisable at basinal scale (Fig. 4.C). ~~So, t~~The base of the Opalinum Subzone therefore has to be established by the FAD of the ~~last one~~latter, and not by its FAD concomitant~~ly~~ with the LAD of *Pleydellia aalensis* (Zieten) (Fig. 6). Similarly, the co-occurrence of *Leioceras opalinum* (Reinecke) and the FAD of *Cypholioceras comptum* (Reincke) at the base of the Comptum Subzone ~~discard~~ ignores the extinction of the ~~first one~~former as ~~criteria~~ criterion for ~~to recognize~~ recognising the Opalinum-Comptum subzone boundary (Fig. 4.J).

The increase in the relative abundance of *Vacekia* representatives ~~at~~ in the upper part of the Comptum Subzone is a relevant bioevent, at least with regional value, allowing the subzone to be ~~recognition~~ recognised ~~of that subzone~~ in sections of the Lusitanian Basin where the last Leioceratinae representatives are generally rare ~~scarce~~ or absent (Fig. 3).

6.2. Foraminiferal record and stratigraphic implications

~~Regarding~~ ~~Concerning~~With regard to benthic foraminifera ~~diversity~~species richness, a total of 57 species where identified ~~for this~~in the stratigraphic interval studied ~~a total of 57 species where identified~~ in the Zambujal de Alcaria section (Figueiredo, 2009; Figueiredo et al., 2010), 45 in the Maria Pares section (Guterres, 2010; Figueiredo and Guterres, 2012) and 35 in the Murtinheira section (Canales and Henriques, 2008), all of ~~them~~ which lie in the Lusitanian Basin. In addition,~~,~~ ~~and~~ a total of 50 species where obtained ~~in~~ from different sections of the Basque-Cantabrian Basin in~~,~~ Northern Spain

(Canales, 2001). In the Moyuela section, located in the Iberian Range (Spain), 47 species were identified along the Upper Toarcian and Lower Aalenian transition (Canales and Herrero, 2000), ~~and~~ whilst in the Fuentelsaz section (Aalenian GSSP), also located in the Iberian Range, a total of 62 species were obtained (Herrero and Canales, 1997). As a consequence, and ~~having~~ taking into account the fact that a total of 71 species have been identified in São Gião ~~a total of 71 species have been identified~~, this section is the most diverse ~~among~~ of the Iberian basins ~~for~~ in terms of this stratigraphic interval.

Regarding the taxonomical composition of the assemblages, as commonly occurs in ~~the~~ Jurassic foraminiferal assemblages from the Boreal Realm, *Lenticulina* (Lagenina Suborder) is the most abundant genus. In the São Gião section, the most abundant species ~~belonging to~~of this genus~~,~~ in almost all of the assemblages~~,~~ is *Lenticulina helios* (Terquem). Canales et al. (2010) have pointed out that the different species of *Lenticulina* recorded in the Lower-Middle Jurassic transition in several sections of the Lusitanian Basin show variations in their relative abundances which can be related to the facies where they ~~were~~ developed. Thus, *Lenticulina muensteri* (Roemer) is relatively more abundant ~~shows its higher relative abundances~~ in facies corresponding to the deeper part of the platform, whilst *Lenticulina helios* (Terquem) attaints ~~its~~ maximum relative abundance in the ~~intermediate zone of the~~middle platform and *Lenticulina toarcense* Payard is ~~the~~ most abundant in facies corresponding to the shallower part (the inner~~of the~~ platform). Other ~~genera of this suborder~~Lagenina genera with unusually high relative abundance~~s~~, such as *Prodentalina*, *Nodosaria* and other elongated forms, corresponding to shallow infaunal morph~~f~~ogroups and indicating good levels of nutrients and oxygenation in the infaunal microhabitats (Reolid et al., 2012) have been recorded in the Comptum Subzone.~~,~~ ~~like *Prodentalina*, *Nodosaria* and other~~

~~elongated forms, corresponding to shallow infaunal morfogroups and indicating good levels of nutrients and oxygenation in the infaunal microhabitats (Reolid et al., 2012)~~. ~~It is also remarkable t~~The abundant record of representatives of the ~~Suborder~~ Miliolina Suborder, which are present in almost all the ~~studied~~ assemblages studied and unusually frequent in the Aalensis and in the upper part of the Comptum subzones, is also notable. ~~Foraminiferal~~ The foraminiferal assemblages recorded are abundant and very diverse. ~~Along~~ Within the ~~studied~~ time span studied, there are no significant dissapearances or ~~appearances~~ occurrences of taxa ~~occur~~. The whole ~~studied~~ stratigraphic interval corresponds to a single foraminiferal zone (the *Astacolus dorbignyi* Zone). For this reason, a total of 11 bioevents, based on FAD, LAD or changes in the observed abundance of some taxon or in ~~the~~ assemblages~~'~~ diversity have been established, representing biostratigraphical proxies generally of local application (Fig. 6). Nevertheless, some of them, e.g. the increase in the relative abundance of *Lenticulina exgaleata* Dieni from the upper part of the Opalinum Subzone to the lower part of the Comptum Subzone, have also been ~~recognized~~ recognised in other coeval sections in the Lusitanian Basin (Canales and Henriques, 2008; Figueiredo, 2009; Figueiredo et al., 2010; Guterres, 2010), ~~showing~~ thus demonstrating ~~as a consequence~~ regional value. The FAD of *Nodosaria hortensis* Terquem in the Aalensis Subzone and the ~~high~~ marked increase in the relative abundance of *Ophthalmidium* representatives in the lower part of the Comptum Subzone have been also ~~recognized~~ recognised in the Zambujal de Alcaria Section (Figueiredo, 2009; Figueiredo et al., 2010;). The increase observed ~~increase~~ in the relative abundance of the Textulariina Suborder ~~Textulariina~~, as well ~~as of~~in *Eoguttulina liassica* (Strickland) in the upper part of the Comptum Subzone have also been ~~also recognized~~ recognised in the Murtinheira section (Canales and Henriques, 2008).

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6.3. Faunal turnovers and seawater palaeotemperatures

A previous study on morphological changes observed in ammonites at the Lias-Dogger boundary, ~~have~~ questionned the existence of a faunal crisis during the Late Toarcian-Early Aalenian times (Neige et al., 2001). The ammonite composition of the assemblages ~~along~~throughout the Upper ~~Taken into account the ammonite composition of the assemblages along the Upper~~ Toarcian-Lower Aalenian record ~~of~~for the São Gião section also~~, the~~ shows a virtually constant rate of faunal turnover ~~is virtually constant,~~ i.e., no drastic changes between the number of originations and the number of extinctions for each ammonite biozone ~~have been recognized~~, unlike the coeval record described for the Betic Cordillera~~,~~. ~~where~~The Toarcian-Aalenian ammonite record is ~~there~~ represented in this case by a major faunal turnover which has been correlated with a sea-level regressive phase (Sandoval et al., 2001b) and ~~with~~ relatively low $\delta^{13}C$ values ~~of~~ for bulk carbonates in the Upper Toarcian, followed by a moderate positive excursion of the $\delta^{13}C_{carb}$ in the Comptum Subzone (Sandoval et al., 2008). This “Comptum cooling~~”~~ event” was also ~~pointed out~~noted by Gómez et al. (2009) for the Basque-Cantabrian Basin (Northern Spain), in relation ~~with~~ to major faunal turnover ~~on~~ in the ammonite and foraminiferal record, and a seawater temperature of 15.7ºC based on $\delta^{18}O_{bel}$ has been proposed for this time interval. Price (2010) proposes a seawater temperature of 15-22ºC for the Early Aalenian with ~~a~~ rapid cooling to a minimum of 7ºC for the Comptum Subzone based on the positive isotopic excursion ~~recognized~~ recognised ~~on~~ in the ~~$\delta^{13}C_{bel}$ and~~ $\delta^{18}O_{bel}$ curves for the Aalenian and Bajocian of Scotland, and ~~argues~~ he therefore supports the global range of the “Comptum cooling~~”~~ event”.

However, the Comptum Subzone of the São Gião section is ~~characterized~~ characterised by the co-occurrence of ~~the Boreal N~~northwest European Leioceratinae taxa and the

~~western Tethysian~~Mediterranean Grammoceratinae, namely the dominant *Vacekia striata* Henriques, which may ~~attain~~ amount to 30% of the total identified species within the whole unit, a feature ~~recognized~~ recognised at basinal scale (Sandoval et al., 2012a). Among the foraminifers, ~~the Miliolina representatives~~miliolids, generally interpreted as typical of shallow waters (Copestake and Johnson, 1981; Haynes, 1981; Stam, 1985; Murray, 1989), ~~show~~ have a continuous and relatively abundant record in this section. This group ~~attains~~ amounts to 19% of the total assemblage from the Comptum Subzone in São Gião, but is ~~scarce~~ rare in the Aalenian GSSP (Herrero and Canales, 1997), and ~~lacks~~ absent in all the coeval sections of the Basque-Cantabrian Basin (Canales, 2001) and ~~in~~ the Northern Iberian Range (Canales and Herrero, 2000). In the Lusitanian Basin, Miliolina is ~~scarce~~ rare in distal and proximal facies (Canales and Henriques, 2008; Figueiredo, 2009; Figueiredo et al., 2010), but ~~attains~~ represents 7% of the relative abundance in intermediate facies (Guterres, 2010; Figueiredo and Guterres, 2012), ~~like~~ such as those of the São Gião section. Regarding the taxonomical composition of the foraminiferal assemblages~~,~~ described in the Basque-Cantabrian Basin (Northern Spain), and ~~related~~ in relation to the “Comptum cooling~~”~~ event”, a total of 14 species ~~show~~ present their FAD ~~along~~ within this time interval (Gómez et al., 2009). Most of them, apparently typical of cool waters, are absent in São Gião and, whenever present, ~~they display a scarce~~ record is scarce, both ~~on~~ in terms of stratigraphic distribution and relative abundance.

As a consequence, the results obtained from the composition~~´s~~al analysis of the ammonite and foraminiferal assemblages recorded in the São Gião section do not support the inferred cooling trend to ~~a~~ the minimum ~~of the~~ seawater temperatures, ~~as well as~~or the global character of the “Comptum cooling~~”~~ event”. Local reasons must be ~~invoked~~ cited in order to justify the warmer seawater temperature trend in the

Lusitanian Basin, as inferred by the ammonite and foraminiferal record along the Lower-Middle Jurassic transition, ~~namely~~ specifically in relation ~~related~~ to the palaeogeographic location of the basin ~~in the frame~~within the context of the opening of the North Atlantic Ocean (García-Frank et al., 2008) and/or the hypothetical connection between Western Tethys and the Eastern Pacific through the Hispanic Corridor (Arias, 2006, 2007; Sandoval et al., 2012a). Hydrothermal activity and/or changes in ~~the~~ oceanic circulation patterns ~~feature~~ are plausible ~~causes to explain~~explanations for the occurrence of warmer seawater temperatures in this sector of the Lusitanian Basin, ~~in opposition~~as opposed to the inferred cool seawater ~~admitted~~ accepted for the neighboring basins.

7~~6~~. Conclusions

The first study ~~for the first time~~ of the co-occurrence of ammonite and benthic foraminiferal assemblages across the São Gião outcrop (Central Portugal) represents a contribution to ~~the~~ knowledge ~~on~~ of this reference section for the Lower-Middle Jurassic boundary of the Lusitanian Basin. The analysis of the macro and microfossil assemblages in this expanded section, both correlatable with the Aalenian GSSP at Fuentelsaz section (Iberian Cordillera, Spain, Cresta et al., 2001), improves the calibration of the biostratigraphic scale for the Lower-Middle Jurassic boundary based on these fossil groups, a particularly important biostratigraphical proxy when ammonites are poorly preserved, scarce or almost impossible to obtain (i.e. in core samples).

A total of well-preserved 447~~63~~ ammonite specimens and 13.~~,~~116 foraminifers have been studied and no evidence of taphonomic processes that could change the original assemblages ~~has been~~were detected.

From a taxonomic point of view, the ammonite record of São Gião section mainly includes ~~mainly~~ some typical ~~Boreal N~~northwest European Grammoceratinae (*Catulloceras, Cotteswoldia, Pleydellia*) in the U~~u~~pper Toarcian, and Leioceratinae (*Leioceras*, *Cypholioceras*) in the L~~l~~ower Aalenian, ~~aside~~ together with typical Mediterranean Grammoceratinae (*Vacekia*), Tmetoceratinae (*Tmetoceras*) and ~~scarce~~ rare Hammatoceratidae (*Bredya* and *Czerneyiceras*). No typically Tethysian phylloceratids ~~have been~~were found among the 20~~32~~ species corresponding to 9 ~~20~~ genera ~~which have been identified~~, but ~~it is remarkable~~ the relative abundance of Grammoceratinae ~~along~~ throughout the ~~studied~~ time interval studied is noticeable, namely *Vacekia striata* Henriques, which may ~~attain~~ account for 26~~30~~% of the total identified species ~~at~~ in the Comptum Subzone. Regarding the foraminifer~~as~~, the recorded assemblages are very abundant and are also the most diverse in the Iberian Peninsula for this time interval. A total of 71 species, corresponding to 26 genera and 5 suborders have been identified, all ~~of them~~ typical ~~from~~ of the Jurassic platforms of the ~~North~~ northern ~~Hemisphere~~hemisphere. Among the ~~recognized~~ recognised suborders, Lagenina can be considered ~~as~~ dominant, *Lenticulina* is the best represented genus, and *Lenticulina helios* (Terquem) is the most abundant species. ~~Nevertheless~~In addition, representatives of the ~~Suborder~~ Miliolina Suborder are also unusually frequent.

The ammonite record of the São Gião section has ~~allowed~~ enabled 4 biostratigraphic units to be recognised ~~the recognition of 4 biostratigraphic units~~ (Mactra and Aalensis ~~Subzones~~ subzones of the Aalensis Biozone in the U~~u~~pper Toarcian, and Opalinum and Comptum ~~Subzones~~ subzones of the Opalinum Biozone in the L~~l~~ower Aalenian). ~~Concerning~~ With regard to benthic foraminifera, the taxa identified have ~~allowed~~ enabled the *Astacolus dorbignyi* Zone to be identified~~the recognition of the *Astacolus dorbignyi* Zone~~, as well as 11 bioevents based on FAD, LAD, and changes in the relative abundance of ~~some~~ certain taxa or changes in ~~the diversity~~species richness in the recorded assemblages.

The constant and continuous ammonite record of ~~Northwest~~ northwest European ~~Boreal~~ taxa, ~~aside~~ together with the typical Mediterranean taxa ~~along~~ throughout the ~~whole~~ section, the relatively high ~~relative~~ abundance of ~~the~~ Miliolina representatives, which are usually interpreted~~generally interpreted~~ as typical of shallow waters, and the absence of typical ~~forms of~~ cool waters forms, do not ~~match~~ concur with the inferred cooling of ~~the~~ seawater temperatures assigned to the Early Aalenian, ~~as well as with~~or the global ~~character~~ nature of the “Comptum cooling~~”~~ event”.

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FIGURE CAPTIONS

Fig. 1. Location of the Lusitanian Basin (West of the Iberian Peninsula), geological map of the Lusitanian Basin showing the Jurassic outcrops and location of the São Gião section (modified after Figueiredo, 2009).

Fig. 2. Synthetic lithostratigraphic chart for the Triassic, Lower and Middle Jurassic of the Lusitanian Basin, showing the position of the São Gião section (modified after Azerêdo et al., 2003).

Fig. 3. Lithological succession in São Gião section, biostratigraphic units based on ammonites and, in black dots with different diameter, occurrence and relative abundance of the identified ammonite taxa along the section.

Fig. 4. ~~(All specimens in natural size).~~ Upper Toarcian and Lower Aalenian selected ammonites recorded in São Gião section. **A.** *Pleydellia subcompta* Branco. SG-6.1. Toarcian, Aalensis Biozone, Mactra Subzone. **B.** *Pleydellia aalensis* (Zieten). SG-9.1. Toarcian, Aalensis Biozone, Aalensis Subzone. **C.** *Pleydellia aalensis* (Zieten). SG-35.1. Aalenian, Opalinum Biozone, Opalinum Subzone. **D.** *Pleydellia folleata* (Buckman). SG-11.4. Toarcian, Aalensis Biozone, Aalensis Subzone. **E.** *Pleydellia fluitans* (Dumortier). SG-35.50. Aalenian, Opalinum Biozone, Opalinum Subzone. **F.** *Pleydellia lotharingica* (Buckman). SG-35.5. Aalenian, Opalinum Biozone, Opalinum Subzone. **G.** *Pleydellia lotharingica* (Buckman). SG-35.71. Aalenian, Opalinum Biozone, Opalinum Subzone. **H.** *Pleydellia folleata* (Buckman). SG-27.17. Toarcian, Aalensis Biozone, Aalensis Subzone. **I.** *Cotteswoldia egena* Buckman. SG-

22.1. Toarcian, Aalensis Biozone, Aalensis Subzone. **J.** *Cotteswoldia limatula* Buckman. SG-22.2. Toarcian, Aalensis Biozone, Aalensis Subzone. **K.** *Leioceras opalinum* (Reinecke). SG-55.49. Aalenian, Opalinum Biozone, Comptum Subzone. **L.** *Leioceras costosum* (Quenstedt). SG-55.31. Aalenian, Opalinum Biozone, Comptum Subzone. **M.** *Leioceras costosum* (Quenstedt). SG-103.1. Aalenian, Opalinum Biozone, Comptum Subzone. **N.** *Cypholioceras lineatum* (Buckman). SG-39.4. Aalenian, Opalinum Biozone, Opalinum Subzone. **O.** *Cypholioceras comptum* (Reinecke). SG-55.32. Aalenian, Opalinum Biozone, Comptum Subzone. **P.** *Vacekia striata* Henriques. SG-43.4. Aalenian, Opalinum Biozone, Opalinum Subzone. **Q.** *Vacekia sourensis* (Perrot). SG-55.1. Aalenian, Opalinum Biozone, Comptum Subzone. **R.** *Vacekia striata* Henriques. SG-102.1. Aalenian, Opalinum Biozone, Comptum Subzone. **S.** *Tmetoceras scissum* (Benecke). SG-33.6. Aalenian, Opalinum Biozone, Opalinum Subzone. **T.** *Tmetoceras scissum* (Benecke). SG-66.1. Aalenian, Opalinum Biozone, Comptum Subzone. **U.** *Bredyia* sp. SG-83.1. Aalenian, Opalinum Biozone, Comptum Subzone. (All specimens in natural size).

Fig. 5. Occurrence and relative abundance of some of the foraminiferal taxa recorded in the ~~studied~~ stratigraphic interval studied.

Fig. 6. Occurrence and relative abundance of some of the foraminiferal taxa recorded in the studied stratigraphic interval (see legend of Fig. 4) and zonal scale based on foraminifers. Main bioevents based on ammonites and on foraminifers identified along the Lower/Middle Jurassic transition in São Gião section.

Fig. 7 ~~(Scale bar 100 μ)~~. Upper Toarcian and Lower Aalenian selected foraminifera corresponding to the suborders Textulariina, Spirillinina, Miliolina and Lagenina. **A.** *Thurammina jurensis* (Franke). SG-56.51.211. Aalenian, Opalinum Biozone, Comptum Subzone. **B.** *Tolypammina flagellum* Terquem. SG-48.103.263. Aalenian, Opalinum Biozone, Opalinum Subzone. **C.** *Ammobaculites coprolithiformis* (Schwager). SG-86.104.264. Aalenian, Opalinum Biozone, Comptum Subzone. **D.** *Ammobaculites fontinensis* (Terquem). SG-74.52.212. Aalenian, Opalinum Biozone, Comptum Subzone. **E.** *Ammobaculites vetustus* (Terquem and Berthelin). SG-86.121.281. Aalenian, Opalinum Biozone, Comptum Subzone. **F.** *Trochammina* cf. *canningensis* Tappan. SG-64.105.265. Aalenian, Opalinum Biozone, Comptum Subzone. **G.** *Spirillina numismalis* Terquem and Berthelin. SG-54.55.215. Aalenian, Opalinum Biozone, Comptum Subzone. **H.** *Spirillina orbicula* Terquem and Berthelin. SG-48.54.214. Aalenian, Opalinum Biozone, Opalinum Subzone. **I.** *Vinelloidea tibia* (Terquem and Berthelin). SG-64.122.282. Aalenian, Opalinum Biozone, Comptum Subzone. **J.** *Ophthalmidium northamptonensis* Wood and Barnard. SG-64.57.217. Aalenian, Opalinum Biozone, Comptum Subzone. **K.** *Prodentalina* cf. *fragilis* (Terquem). SG-64.124.284. Aalenian, Opalinum Biozone, Comptum Subzone. **L.** *Prodentalina* cf. *guembeli* (Schwager). SG-64.67.227. Aalenian, Opalinum Biozone, Comptum Subzone. **M.** *Prodentalina pseudocommunis* (Franke). SG-32.65.225. Toarcian, Aalensis Biozone, Aalensis Subzone. **N.** *Prodentalina subsiliqua* (Franke). SG-62.66.226. Aalenian, Opalinum Biozone, Comptum Subzone. **O.** *Falsopalmula jurensis* (Franke). SG-86.69.229. Aalenian, Opalinum Biozone, Comptum Subzone. **P.** *Falsopalmula obliqua* (Terquem). SG-54.70.230. Aalenian, Opalinum Biozone, Comptum Subzone. **Q.** *Nodosaria fontinensis* Terquem. SG-74.72.232. Aalenian, Opalinum Biozone, Comptum Subzone. **R.** *Nodosaria hortensis* Terquem. SG-

56.73.233. Aalenian, Opalinum Biozone, Comptum Subzone. **S.** *Nodosaria liassica* Barnard. SG-54.4.234. Aalenian, Opalinum Biozone, Comptum Subzone. **T.** *Nodosaria pseudoregularis* Canales. SG-96.125.285. Aalenian, Opalinum Biozone, Comptum Subzone. **U.** *Nodosaria pulchra* (Franke). SG-86.76.236. Aalenian, Opalinum Biozone, Comptum Subzone. **V.** *Nodosaria simoniana* d'Orbigny. SG-90.110.270. Aalenian, Opalinum Biozone, Comptum Subzone. **W.** *Nodosaria torulosi* Frentzen. SG-86.111.271. Aalenian, Opalinum Biozone, Comptum Subzone. **X**. *Pseudonodosaria vulgata* (Bornemann). SG-96.126.286. Aalenian, Opalinum Biozone, Comptum Subzone. **Y.** *Lenticulina bochardi* (Terquem). SG-86.127.287. Aalenian, Opalinum Biozone, Comptum Subzone. (Scale bar 100 µ).

Fig. 8 ~~(Scale bar 100 µ)~~. Upper Toarcian and Lower Aalenian selected foraminifera corresponding to the suborders Lagenina and Robertinina. **A.** *Lenticulina constricta* (Kaptarenko-Chernousova) *sensu* Jendryka-Fuglewicz. SG-68.80.241. Aalenian, Opalinum Biozone, Comptum Subzone. **B.** *Lenticulina exgaleata* Dieni. SG-54.81.241. Aalenian, Opalinum Biozone, Opalinum Subzone. **C.** *Lenticulina helios* (Terquem). SG-32.82.242. Toarcian, Aalensis Biozone, Aalensis Subzone. **D.** *Lenticulina muensteri* (Roemer). SG-8.83.243. Toarcian, Aalensis Biozone, Mactra Subzone. **E.** *Lenticulina polygonata* (Franke). SG-48.84.244. Aalenian, Opalinum Biozone, Opalinum Subzone. **F.** *Lenticulina toarcense* Payard. SG-62.129.289. Aalenian, Opalinum Biozone, Comptum Subzone. **G.** *Astacolus dorbignyi* (Roemer). SG-56.130.290. Aalenian, Opalinum Biozone, Comptum Subzone. **H.** *Astacolus scalptus* (Franke). SG-64.88.248. Aalenian, Opalinum Biozone, Comptum Subzone. **I.** *Astacolus vetustus* (d'Orbigny). SG-34.113.273. Aalenian, Opalinum Biozone, Opalinum Subzone. **J.** *Marginulina* aff. *ambigua* (Schwager). SG-62.90.250. Aalenian, Opalinum Biozone, Comptum Subzone.

K. *Marginulina scapha* (Lalicker). SG-52.91.251. Aalenian, Opalinum Biozone, Comptum Subzone. **L.** *Citharina clathrata* (Terquem). SG-38.92.252. Aalenian, Opalinum Biozone, Opalinum Subzone. **M.** *Citharina colliezi* (Terquem). SG-78.93.253. Aalenian, Opalinum Biozone, Comptum Subzone. **N.** *Citharina* cf. *ornithocephala* (Wiśniowski). SG-64.95.255. Aalenian, Opalinum Biozone, Comptum Subzone. **O.** *Planularia beierana* (Gümbel). SG-32.115.275. Toarcian, Aalensis Biozone, Aalensis Subzone. **P.** *Planularia protracta* (Bornemann). SG-48.98.258. Aalenian, Opalinum Biozone, Opalinum Subzone. **Q.** *Eoguttulina liassica* (Strickland). SG-64.99.259. Aalenian, Opalinum Biozone, Comptum Subzone. **R.** *Ramulina* cf. *spandeli* Paalzow. SG-64.100.260. Aalenian, Opalinum Biozone, Comptum Subzone. **S.** *Bullopora rostrata* Quenstedt. SG-32.102.262. Toarcian, Aalensis Biozone, Aalensis Subzone. **T.** Internal mould of a specimen belonging to the Family Ceratobuliminidae. SG-56.116.276. Aalenian, Opalinum Biozone, Opalinum Subzone. (Scale bar 100 μ)