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COMMENTARY

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1 | INTRODUCTION

We want to acknowledge the comments about our recently published paper. The exchange of ideas, data and interpretation improves our knowledge and is the right way to discuss science's advances.

This reply considers the points raised by Azerêdo et al. (2023) and Schneider et al. (2023). In both manuscripts, these authors raised many issues about sedimentological and stratigraphic aspects that can be separated into two groups: (a) those related to the age of the studied succession; and (b) those assigning the studied succession to the Candeeiros Formation.

2 | THE BATHONIAN–EARLY CALLOVIAN AGE

There is a long tradition of using macropalaeontology in the Lusitanian Basin, and many authors have used macrofossils as palaeoenvironmental indicators and to date sedimentary deposits. However, except for ammonoids, micropalaeontology data are much more accurate than those from corals or bivalves, for example. This is particularly important in the Consolação–São Bernardino succession because of the lack of micropalaeontological and biostratigraphical studies.

It is noteworthy that Magalhães et al. (2023) presented a hitherto unpublished micropalaeontological and biostratigraphical analysis of the Consolação–São Bernardino succession. The association of two fossil groups (calcareous nannofossil and dinoflagellates) support our biostratigraphic data, in which we performed taxonomic and biostratigraphic analyses with care and due importance. Hence, our analysis assures the age of the studied succession, which confirms the Bathonian–early Callovian age. Azerêdo et al. (2023) and Schneider et al. (2023) questioned our age assignments, but failed to present their micropalaeontological and biostratigraphical analysis for the same Consolação–São Bernardino succession. Moreover, our findings were integrated with facies analysis, ichnofacies, petrography and macrofossil content to support the proposed age. Azerêdo et al. (2023) and Schneider et al. (2023) have no doubts about the taxonomy presented, and their issues about our dating are based on reinterpretations of our data. They assumed that the literature had already defined the age of the studied succession, which we consider is beyond debate as a result of the new data. That paper acknowledged the previous studies in the Consolação-São Bernardino section. Still, the arguments by Azerêdo et al. (2023) and Schneider et al. (2023) are not based on micropalaeontological data collected in the Consolação-São Bernadino section, but rather on correlations with supposed chronoequivalent units that do not consider our new age. Their comments failed to include irrefutable evidence of the Upper Jurassic age based on micropalaeontological data from the Consolação–São Bernardino succession to contrast with dates presented by Magalhães et al. (2023).

New data bring new interpretations. Even though all issues raised by Azerêdo et al. (2023) and Schneider et al. (2023) are welcome, they need to be supported by comparable data collected from the Consolação–São Bernardino succession. Those authors offered correlations with other sections and dating from previous studies but failed to present new micropalaeontological and biostratigraphic dating evidence from the Consolação–Sâo Bernardino succession. Therefore, it is not acceptable to state that the paper by Magalhães et al. (2023) needs to provide a better interpretation based on the correlation of data from supposed chrono-equivalent lithological units. We affirm they are not. For instance, Azerêdo et al. (2023) and Schneider et al. (2023) argued that reworking might explain our microfossil data. However, there is no sedimentological evidence for the proposed reworking. At the base of the section, calcispheres occur associated with the highest concentration of calcareous nannofossils in the outer ramp facies association. Facies analysis and microfossil content indicate this facies association was deposited in an environment of relatively deep and calm waters incompatible with the energy level required to rework, transport and deposit older Middle Jurassic sediments. This conclusion is supported by evidence and discussion presented in section 4 'Results' and section 5 'Discussion' of our paper. Again, it is not true as contended by Azerêdo et al. (2023) and Schneider et al. (2023) that the paper by Magalhães et al. (2023) lacks data supporting interpretation.

2.1 | About calcareous nannofossil analysis

For the calcareous nannofossil analysis, the criteria for the taxonomic identifications are mostly based on the Farinacci and Howe catalogue, which is extensively used to establish the taxonomy of the Nannotax3 website (see Young et al., 2022), and contains the primary literature for the recovered species. The biostratigraphic framework presented by Magalhães et al. (2023) shows a synthesis of the calcareous nannofossil assemblage observed in the Consolação–São Bernardino succession. Thus, the Bathonian–early Callovian age attribution was based on the co-occurrence of *Watznaueria barnesiae*, *W. britannica*, *W. manivitiae*, *Cyclagelosphaera margerelii*, *Lotharingius velatus*, *L. hauffii*, *L. contractus* and *Similiscutum novum*. The stratigraphic distribution of these species was mainly based on the Tethyan biostratigraphic framework of Mattioli and Erba (1999), as well as on the stratigraphic ranges published on the Nannotax3 website (Young et al., 2022) for some studied species (*S. novum*, *L. hauffii*, *L. sigillatus* and *Parhabdolithus liasicus*) that were compiled in this website according to the NW Europe biostratigraphic scheme of Bown and Cooper (1998). Below we reinforce our interpretation and demonstrate the arguments of Azerêdo et al. (2023) and Schneider et al. (2023) are flawed.

Azerêdo et al. (2023) wrote:

> Several inconsistencies arise because Magalhães et al. (2023) mix Boreal and Tethyan biostratigraphic schemes.

as well as:

> The micropalaeontological data used to revise the section's age as Middle Jurassic are not robust, and the age interpretations are oversimplified or inaccurate, because of, for example, confusion between the Boreal and Tethyan biostratigraphic schemes.

These claims are only based on reinterpretations of the micropalaeontological data presented by Magalhães et al. (2023) without offering their micropalaeontological data from the Consolação–Sâo Bernardino succession. They also show a misinterpretation of the bioprovinces and ranges of some of the species (*W. manivitiae*, *S. novum*, *L. sigillatus* and *L. hauffii*) studied by Bown and Cooper (1998) and Mattioli and Erba (1999). The Ferreira et al. (2019) study of calcareous nannofossils, carried out in five late Sinemurian–early Bajocian sections of the Lusitanian Basin (Western Portugal), is used here to explain these discrepancies. Below we demonstrate there is no mix between Boreal and Tethyan biostratigraphic schemes.

2.2 | About *Watznaueria manivitiae*

According to the NW Europe biostratigraphic scheme by Bown and Cooper (1998), the first occurrence (FO) of *W. manivitiae* was observed as occurring within the late Bathonian–early Callovian interval in the predominantly Tethyan taxa table (page 45 of Bown & Cooper, 1998). However, these authors also indicate the FO of this species in the lower part of the Bajocian (page 37; according to Italy/South France biostratigraphic framework, Mattioli et al. apud. Bown & Cooper, 1998). Considering this inconsistency, Magalhães et al. (2023) use the FO of *W. manivitiae* as suggested by Mattioli and Erba (1999), who proposed a Tethyan biostratigraphic scheme using sites from Northern and Central Italy, which was also correlated with Portugal, Morocco, Switzerland and Boreal realm sites. As a result, the FO of *W. manivitiae* was considered an excellent biostratigraphic event within the middle/early Bajocian (Mattioli & Erba, 1999). In addition, the FO of *W. manivitiae* was used by Mattioli and Erba (1999) to define the base of the NJT 10 Zone (with the top being limited by the FO of *W. barnesiae*). Thus, this zone indicates a late/early Bajocian to earliest Bathonian interval. For the Lusitanian Basin, the FO of *W. manivitiae* marks the NJT 10 Zone in the Cabo Mondego Section (Ferreira et al., 2019). Magalhães et al. (2023) use the FO of *W. manivitiae* based on the Tethyan biostratigraphic scheme of Mattioli and Erba (1999); hence, there is no mix between Boreal and Tethyan biostratigraphic schemes.

2.3 | About *S. novum* and *L. sigillatus*

The last occurrences (LOs) of *S. novum* and *L. sigillatus* occur at the Bathonian–Callovian boundary (Bown & Cooper, 1998; Young et al., 2022). Similar and even older biostratigraphic ranges show that the LOs of these species were reported for Tethyan sites (Mattioli & Erba, 1999; and the references therein). As previously mentioned, Mattioli and Erba (1999) also compared their biostratigraphic results with data from other studies developed in several sections of the Tethys and Boreal realms.

Azerêdo et al. (2023) wrote:

> Mattioli and Erba (1999) recorded the LO of *S. novum* in the Tethyan Aalenian.

Azerêdo et al. (2023) might have confused the LO of *S. novum*, which occurs during the early Bajocian based on the distribution scheme of Mattioli and Erba (1999, p. 353), marked as number 10, with that of another species.

For the LO of *L. sigillatus*, Azerêdo et al. (2023) wrote:

> Moreover, Mattioli and Erba (1999) also identify the LO of *L. sigillatus* (mentioned in table 3 and supplementary data S2 of Magalhães et al., 2023) in the Aalenian.

The LO of *L. sigillatus* was observed in the Callovian for the Tethyan sites by Mattioli and Erba (1999, page 354, number 11), in the early Bajocian–Callovian interval in the biostratigraphic scheme of Bown and Cooper (1998) (Mattioli & Erba, 1999) and in the Aalenian according to Kaenel et al. (1996). In a previous study in the Lusitanian Basin, the last consistent occurrence (LCO) of *S. novum* was observed in the NJT 8b Subzone, which spans the middle/late Toarcian interval of the Brenha Section (Ferreira et al., 2019). The LO of *S. novum* was also observed in the NJT 9c Subzone, which encompasses the early Bajocian of the Cabo Mondego Section (Ferreira et al., 2019).

2.4 | About *L. hauffii* and *P. liasicus*

Previous studies indicate that the LO of *L. hauffii* is either at the Callovian (Bown & Cooper, 1998; Mattioli & Erba, 1999; Young et al., 2022) or at the late Oxfordian stage, with the subject needing further investigation (Casellato, 2010). Considering these discrepancies in the biochronostratigraphic position of the LO of *L. hauffii*, we suggest further studies in the Lusitanian Basin to calibrate this event better.

Azerêdo et al. (2023) wrote:

> Magalhães et al. refer to the Early Jurassic species *Parhabdolithus liasicus* from one sample, which they considered to be reworked. But for the rest of the assemblage, reworking in the context of detrital influxes is not mentioned.

As mentioned before, reworking is possible in all sedimentary sections worldwide. Yet, this hypothesis must be supported by sedimentological analysis, which is not the case in the Consolação–São Bernardino succession.

Magalhães et al. (2023) calcareous nannofossil and dinoflagellate biostratigraphic frameworks are new to the Consolação-São Bernardino section. Still, they are well supported by the recovered assemblages, in which we essentially applied the distribution ranges of Mattioli and Erba (1999). While future studies are necessary to complement the knowledge about the calcareous nannofossil occurrences in the Lusitanian Basin, our data allow for a confident interpretation supported by previously published Tethyan Jurassic biostratigraphic schemes.

2.5 | About dinoflagellates

As many of the species of dinoflagellates found by Magalhães et al. (2023) have a wide biostratigraphic range, we decided to calibrate this dinocyst assemblage with the distribution of calcareous nannofossils.

Azerêdo et al. (2023) wrote:

> In our view, this is an oversimplified approach: not all taxa mentioned are diagnostic of a Middle Jurassic age, and abundances are also an important aspect.

We emphasise that the dinoflagellates assemblage described in Magalhães et al. (2023), according to the referenced studies (Borges et al., 2012; Riding, 2005; Riding & Thomas, 1992), is characteristic of the Bajocian–Callovian interval. Nevertheless, it does not mean that the range of some of these taxa does not extend beyond it. It is important to highlight that we are talking about the assemblage. Therefore, not all of its taxa must obligatorily be diagnostic of a specific age or abundance. It is also vital to highlight that the abundance of organisms depends on environmental context, mainly the physical–chemical conditions of ecosystems. For biostratigraphy, however, abundance is only relevant for ACME Zones, of which none were used. The low diversity observed in the study is comparable to what Borges et al. (2012) described for the Algarve Basin in southern Portugal.

Azerêdo et al. (2023) wrote:

> The taxa *Ctenidodinium cornigerum*, *Gonyaulacysta jurassica* subsp. adecta (*Gonyaulacysta adecta* in Riding et al., 2022) and *Pareodinia ceratophora*, are more abundant in the Bathonian and Callovian, but may also occur through the Upper Jurassic, especially in the Oxfordian (Borges et al., 2011; Correia et al., 2019; Feist-Burkhardt & Wille, 1992; Jan du Chêne et al., 1985; Riding et al., 2022; Smelror, 2021; Riding & Thomas, 1992).

The fact that they are not abundant in the studied material does not mean that the samples are of the Oxfordian age. For instance, the low abundance could be justified due to poor preservation or local palaeoenvironmental factors. In addition, most of the publications referenced in the reply (Borges et al., 2011; Correia et al., 2019; Jan du Chêne et al., 1985; Riding et al., 2022; Riding & Thomas, 1992; Smelror, 2021) do not contain any record of *C. cornigerum* in the Oxfordian. It is important to highlight that *C. cornigerum* is considered a typical species of Bajocian–Bathonian transition (Correia et al., 2019; Feist-Burkhardt & Monteil, 1997; Feist-Burkhardt & Wille, 1992; Jan du Chêne et al., 1985; Riding & Thomas, 1992; Wiggan et al., 2017) or Callovian (Borges et al., 2011, 2012), in addition to two occurrences in the Callovian according to the software Palynodata Inc and White (2008). Thus, the dinocyst association common to the Callovian is corroborated by the LO of *C. cornigerum* (Borges et al., 2011, 2012) as well as by the distribution of calcareous nannofossils, here considered not to be younger than Callovian. It is worth noting that Riding and Thomas (1992) was referred in the text of Azerêdo et al. (2023).

According to Azerêdo et al. (2023):

> It is well established that *Meiourogonyaulax* and *Sentusidinium* occur from the Bajocian onwards, and various species span the later Mesozoic.

Considering this information, we consider the distribution of the genera *Meiourogonyaulax* and *Sentusidinium* in a Bathonian–Callovian assemblage to be consistent. Moreover, the biochronostratigraphic range of some species of these genera in younger sections does not invalidate the age interpretation proposed by Magalhães et al. (2023). Future studies are suggested for a refinement in the taxonomic classification of microfossils.

Azerêdo et al. (2023) wrote:

> Forms of *Systematophora* occur in the Bathonian/Callovian interval, but confident species assignments are usually possible only in the Upper Jurassic (Borges et al., 2011; Feist-Burkhardt & Wille, 1992; Riding & Thomas, 1992; Smelror, 2021). The holotype of *Systematophora penicillata* is of late Oxfordian age, so the presence of this species is more indicative of a Late, rather than Middle, Jurassic age.

Systematophora is common in the Upper Jurassic, but there are records of it occurring during the Bathonian/Callovian as well (Borges et al., 2012). In addition, the comments of Azerêdo et al. (2023) and Schneider et al. (2023) about *S. penicillata* indicate an Upper Jurassic age just because its holotype was described from Oxfordian strata. We consider this interpretation incorrect. The occurrence of *S. penicillata* between the Bathonian and the Kimmeridgian was evidenced by diverse studies (Borges et al., 2012; Fauconier et al., 1996; Smelror, 1993; Smelror et al., 1991). Thus, it is reliable that this species occurs in a Callovian assemblage.

Schneider et al. (2023) wrote:

> *Systematophora penicillata* is indicative of a late Oxfordian age according to Williams et al. (2017)… while it is displayed as Bajocian to top Callovian by Magalhães et al. (2023…).

Regarding the age of this taxon, as reported by Williams et al. (2017):

> The age cited for each taxon of species or infraspecific rank is, unless otherwise specified, that attributed to it in the protologue. The age cited in the Index is not intended to be a full or up-to-date statement of the range of the species; users are advised to consult the literature for potentially more detailed and precise information (p. 6).

Thus, Williams et al. (2017) advise users to be careful and observe that 'The age cited in the Index is not intended to be a full or up-to-date statement of the range of the species'. This argument contradicts Schneider et al. (2023). Moreover, Williams et al. (2017) indicate that age assignment should be more than just as described in his catalogue, which shows only the age attributed to the holotype.

Tahoun et al. (2012) recorded an assemblage characteristic of the Callovian–?Kimmeridgian (*Acanthaulax* sp. cf. *A. crispa*, *Amphorulacysta*? *dodekovae*, *Epiplosphaera reticulospinosa*, *Lithodinia jurassica*, *Meiourogonyaulax reticulata*, and *Sentusidinium* spp.). The Kimmeridgian age is indicated by the presence of *Amphorulacysta*? *dodekovae* and *Epiplosphaera reticulospinosa*, making their biostratigraphy ambiguous, according to Riding (2020). In Magalhães et al. (2023), we noticed the presence of *Amphorulacysta* in a Callovian assemblage, similar to Tahoun et al. (2012), suggesting that this genus can occur in rocks older than the Kimmeridgian. Considering these discrepancies in the biochronostratigraphic position of *Amphorulacysta*, we recommend further studies in the Lusitanian Basin to calibrate the range of this genera better.

3 | ASSIGNING TO THE CANDEEIROS FORMATION, A NEW DEPOSITIONAL MODEL, AND THE MIDDLE–UPPER JURASSIC DISCONFORMITY

Once the Bathonian–early Callovian age was established, the assignment to the Candeeiros Formation was evident since it is the lithological unit tied to that age. Again, assuming the Candeeiros consists only of carbonate avoids any possibility of enhancing the understanding of this lithological unit. The local variation from carbonate to mainly siliciclastic lithology in the study area is explained by the terrigenous input from the basin's border. This input is evident in nearby Early Jurassic units (Cabo Carvoeiro Formation, Peniche section), indicating the proximity of a western border. The same palaeogeography could explain the Middle Jurassic input of siliciclastics to the studied area, which would become predominant in Late Jurassic times.

The detailed facies analysis, incorporating ichnofacies and fossil content, and the multicyclic stratal stacking pattern improved the depositional model. Depositional facies were described at a 1:40 scale to capture slight changes and enough evidence to propose the depositional model. For instance, recognising *Skolithos*, *Cruziana* and *Glossifungites* Ichnofacies helped envisage a more appropriate palaeoecological evolution through time. This is the first time hummocky cross-stratified sandstone and sharp-based shoreface strata deposited during forced regression were recognised in the Consolação-São Bernardino section. How could they be formed in shallow, protected water settings? Therefore, the previous interpretation of deposition in shallow, protected waters is inappropriate following the evidence presented in Magalhães et al. (2023).

The Upper Jurassic age, lithological characteristics and depositional systems associated with the Lourinhã Formation are widely accepted (Taylor et al., 2014 and references herein). For instance, the fluvial strata and reddish palaeosol interval at the bottom of the Lourinhã Formation attests to continental origin. The contact between the Lourinhã and Candeeiros formations is seen in São Bernardino. In this location, the contrast between the characteristics of these units is evident, with continental strata from the Lourinhã Formation truncating offshore siltstone and shoreface sandstone from the Candeeiros Formation. Therefore, recognising the Middle–Upper Jurassic disconformity at the contact between the Candeeiros and Lourinhã formations is straightforward. Besides erosive, this surface encompasses a significant hiatus, as demonstrated by the sequence stratigraphic framework.

The local diapir-related uplift explains the absence of the lower units of the Upper Jurassic (Cabaços and Montejunto formations) in the studied area. This uplift is responsible for the significant regional thickness changes in the Upper Jurassic units, as seen, for example, to the east and west of the Lourinhã fault. In this western basin area, close to the Bolhos and Caldas da Rainha diapirs, the Oxfordian to Kimmeridgian units probably were thinner and eroded or absent. Therefore, the basinwide Middle–Upper Jurassic disconformity has a different signature in the studied section.

4 | CONCLUSION

The Magalhães et al. (2023) paper presents an innovative methodology to integrate and interpret the variety of data gathered in their research. Such an approach, based on micropalaeontological, ichnofacies and facies analysis supporting a new depositional model and a novel sequence stratigraphic framework, assures a much more robust interpretation than the more traditional approach founded on separated methods presented by previous authors.

New studies in the Consolação-São Bernardino section are welcome to complement the knowledge about the Lusitanian Basin, such as our work seeks. The discussion remains open and is welcome. Meanwhile, we are waiting for evidence of an irrefutable Upper Jurassic age and depositional systems characterisation from the Consolação–São Bernardino succession that explain the observed data and disagree with the findings of Magalhães et al. (2023).

Our attempts at calibrating the age for these deposits using dinoflagellates and calcareous nannofossils contribute to the comprehension of this basin's depositional evolution and biochronostratigraphy. Moreover, our review covered all data we gathered in this research, which confirmed the interpretation of the depositional facies, the depositional system, the sequence stratigraphic framework and the assignment of the Consolação–São Bernardino succession to the Candeeiros Formation.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analysed in this study.

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