

A compendium of updated Shallow Benthic Zones for the Paleogene and the Miocene

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ABSTRACT: This work provides a complete update for both Shallow Benthic Zones (SBZ) and Orthophragminid zones (OZ) based on Cenozoic larger foraminifera, including the recently proposed SBP for the Paleocene. The proposed zonation considers the time span from Danian to Tortonian, thus including the entire Paleogene and part of the Neogene. According to the most recent literature, here we propose a correlation of shallow-water biozones with the established planktonic biozones, geomagnetic chronozones, and standard chronostratigraphy using the most recent Geological Time Scale (GTS), available from 2020. This study illustrates and describes all data used to tie each single SBZ and SBP to enable the correlation to the chronostratigraphic chart. The OZ boundaries have been moved accordingly, as they are defined based on their relationship with SBZ.

This study considers all those bioevents retrieved along stratigraphic succession within the Tethyan realm and does not consider yet the Letter Zonation for the Indo-Pacific bioprovinces. A comprehensive biostratigraphic correlation between Letter Stages and SBZ would indeed be beneficial for biostratigraphic studies in the region, but a mandatory step would be the definition of middle- to far- east SBZ boundaries, which, differing from those in the Tethyan region, are not yet well defined in the available literature.

INTRODUCTION

The Shallow Benthic Zones (SBZ) system is a consolidated framework widely used in biostratigraphy since its introduction back in the late 1990s (Cahuzac and Poignant 1997; Serra-Kiel et al. 1998). It has its roots in the larger foraminiferal biozones initially proposed by Hottinger (1960, 1974) for alveolinids, Schaub (1981) for nummulitids and Less (1987) for orthophragmines (= families Discocyclinidae and Orbitoclypeidae). The SBZ scheme was first introduced by Serra-Kiel et al. (1998) for the Paleocene to Eocene (SBZ 1-20) and by Cahuzac and Poignant (1997) for the Oligocene to Miocene (SBZ 21-26). However, the original definitions, often based on the first and last appearances of key taxa assemblages (Oppelian zones), presented challenges in precise correlation with the standard chronostratigraphic scale due to their inherently fuzzy boundaries (Pignatti and Papazzoni 2017).

In recent years, a comprehensive, multi-disciplinary initiative has been underway to overhaul and recalibrate the SBZ system. This movement toward a more robust and integrated framework is essential for improving the zonation's precision and international utility, particularly as it aligns with magnetostratigraphy or nannofossils and planktonic foraminifera biostratigraphy. Recent advancements in micropaleontology demand a shift from these traditional "Oppel zones" toward a more calibrated, high-resolution stratigraphic model. Our goal is to move towards an updated and calibrated shallow-water biozonation ensuring that this essential tool remains robust in the face of modern chronostratigraphic requirements and global paleoenvironmental reconstructions. For this reason, we here present an updated zonation scheme that integrates these diverse data streams, following the last revision proposed by Papazzoni et

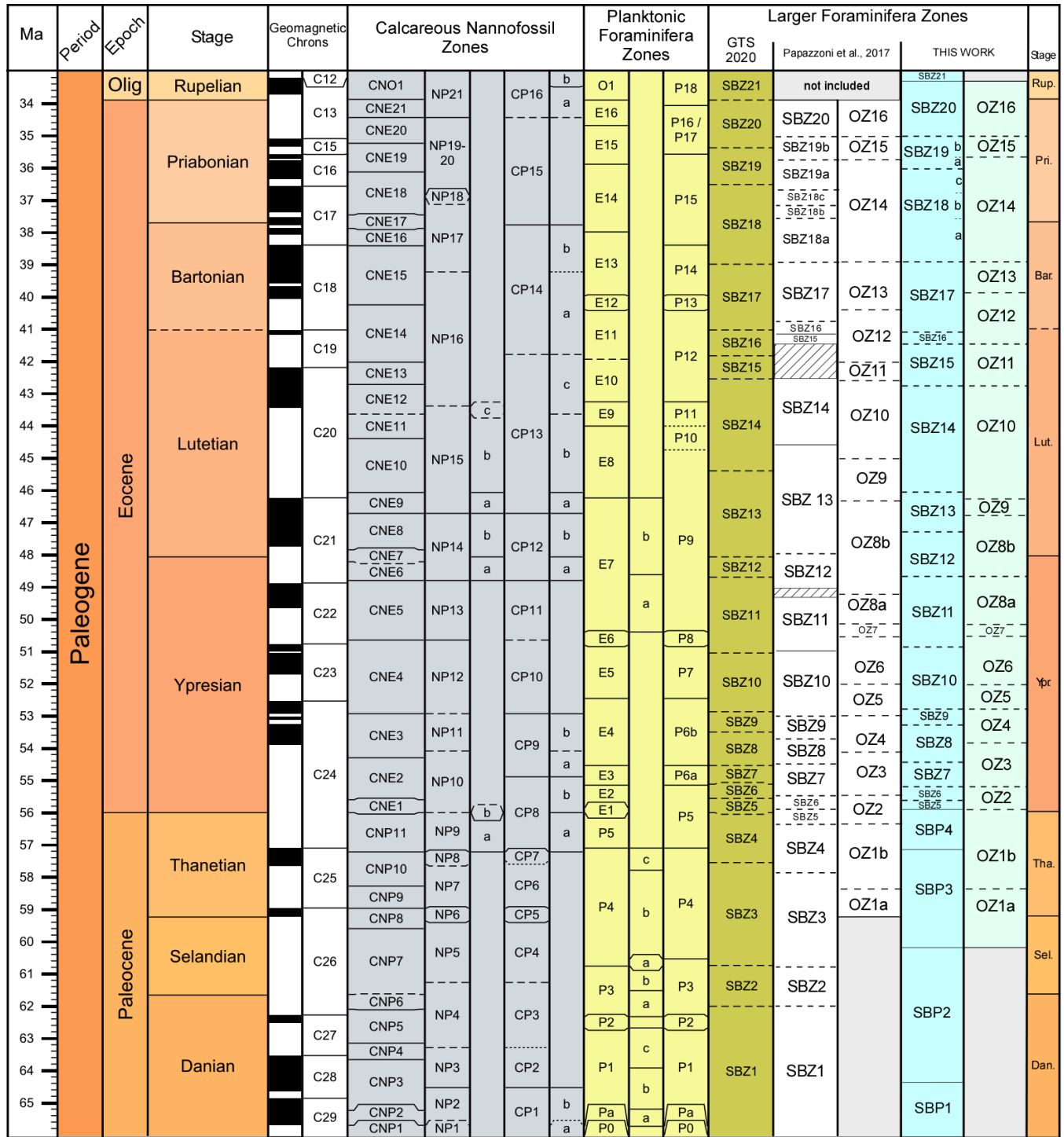
al. (2017) for the Paleocene–Eocene and extending it to the Oligocene and Miocene as well. Due to the large amount of information included into the new biochronostratigraphic chart, this has been split into two segments: the first one starts at the base of the Danian stage at 66 Ma and ends at 33 Ma in the lower Rupelian (text-fig. 1); the second one starts in the upper Priabonian at 35 Ma and ends with the Tortonian/Messinian boundary (text-fig. 2). The 2 Ma overlap in the figures around the Eocene/Oligocene boundary seemed mandatory to enhance clarity. The biochronostratigraphic chart here proposed is based on the Standard Chronostratigraphy as available from TS Creator (v.8.1; 2026 available at <https://timescalecreator.org/>) that includes the Geologic Time Scale 2020 database by Gradstein et al. (2020). The same database includes and correlates the Geomagnetic Polarity, which underwent significant changes with respect to the 2012 version, and the plankton zonation also significantly modified since 2012. All respective references are included into Gradstein et al. (2020).

LARGER FORAMINIFERAL BIOZONE DEFINITIONS SBP1

The base of SBP1 coincides with the base of the Danian at the Cretaceous/Paleogene boundary.

SBP2

The base of SBP2 is defined by Papazzoni et al. (2023) with the first occurrence of *Elazigina dienii* at 64.36 ± 0.19 Ma in correspondence with the lower part of C28n. According to the GTS 2020, it lies within CNP3 and NP3 biozones. In respect to the previous SBZ biozonation, SBP1 is much shorter than SBZ1 (sensu Papazzoni et al. 2017, which basically maintained what Serra-Kiel et al. 1998 proposed), similarly to what reported by



TEXT-FIGURE 1
Biostratigraphic chart for the Paleocene and Eocene epochs.

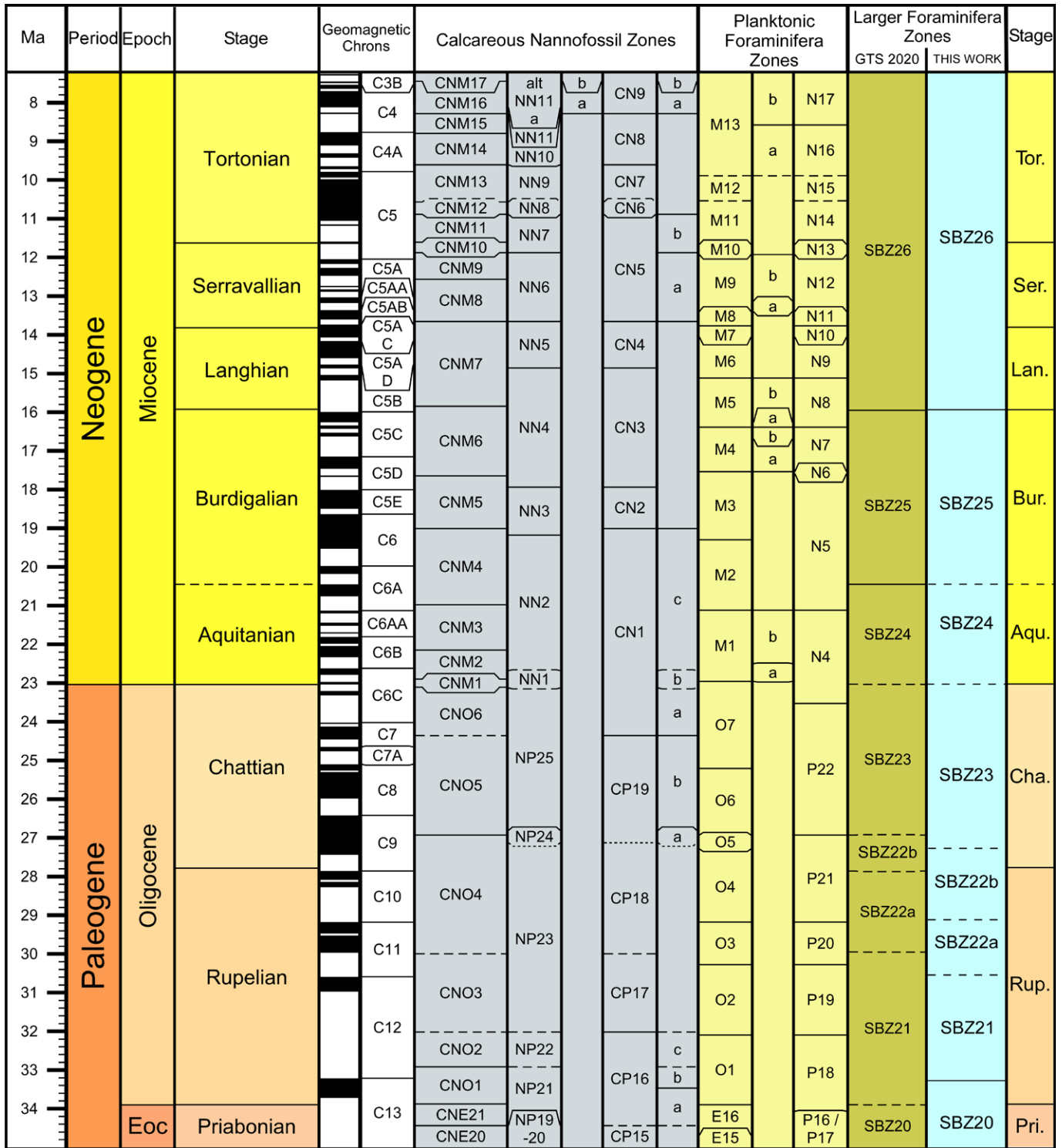
Serra-Kiel et al. (2020).

SBP3

The base of SBP3 is defined by Papazzoni et al. (2023) with the first occurrence of orthophragmines at 60.16 ± 0.18 Ma. It correlates with the upper part of NP5 and CNP7. This new boundary is now slightly younger than previously indicated by Serra-Kiel et al. (1998).

SBP4

The base of SBP4 is defined by Papazzoni et al. (2023) with the first occurrence of *Assilina azilensis*, tentatively positioned at 57.12 ± 0.15 Ma, until more data become available. It possibly correlates with the beginning of C24r, making this biozone much shorter than previously indicated by Serra-Kiel et al. (1998) and again similarly to what reported in Serra-Kiel et al. (2020).



TEXT-FIGURE 2
Biochronostratigraphic chart for the Oligocene and Miocene epochs.

SBZ5

The base of SBZ5 is just above the onset of the CIE (therefore within the lowermost part of the Ypresian), as reported by Scheibner and Speijer (2009), Drobne et al. (2014), Kamran et al. (2021, 2026), Ali et al. (2025). The total duration of SBZ5 (= body CIE) is about 250,000 years according to Jones et al. (2025). It is de-

finied by the first appearance of large alveolinids with the species *Alveolina vredenburgi*. The genus *Alveolina* already appeared in SBP4 with the small *A. korresensis* (Serra-Kiel et al. 2020).

SBZ6

The base of SBZ6 is correlated to the base of CNE2 according

to Serra-Kiel et al. (2020), relatively younger than previously indicated by Papazzoni et al. (2017).

SBZ7

The base of SBZ7 is here tentatively correlated to the base of P6a, based on Serra-Kiel et al. (2020). Indeed, the authors do not specifically discuss SBZ7 in their work but propose a possible correlation, which, after the modifications towards younger ages of both SBZ5 and 6, seems completely reasonable.

SBZ8

The base of SBZ8 is slightly above the base of E4 (and consequently P6b) according to Pirkenseer et al. (2013) and in the upper part of NP10.

SBZ9

The base of SBZ9 is positioned following Mochales et al. (2012, Fig. 10), correlated to the base of Chron 24n.2r (see also Pirkenseer et al. 2013, Fig. 8), and lies within the uppermost part of CNE3. Hadi et al. (2026a, Fig. 3) correlate the base of SBZ9 with the CNE3/4 boundary; however, the boundary shall be positioned halfway between the appearance of *A. citrea*, marker of SBZ9, and the last sample yielding *A. decipiens*, marker of SBZ8; therefore within the uppermost part of CNE3.

SBZ10

The base of SBZ10 is positioned according to Hadi et al. (2026a, Fig. 3) within CNE4, because the turnover *A. trempina* (SBZ9)–*A. canavarii* (SBZ10) occurs in this biozone. According to the magnetostratigraphic data reported by Mochales et al. (2012, Fig. 10) this boundary seems located within Chron 24n.1n.

SBZ11

The base SBZ11 is positioned according to Pueyo et al. (2022, Figs. 10 and 13) for the correlation with magnetostratigraphy, in correspondence with the uppermost part of C23n.1n.

SBZ12

The base of SBZ12 is positioned according to Rodríguez-Pintó et al. (2022, Figs. 14–15) for the correlation with magnetostratigraphy; it lies just after the beginning of C21r and in the lowermost part of CP12a within NP14. With this new definition, the base of SBZ12 seems to be very close to where it was originally proposed by Serra-Kiel et al. (1998).

SBZ13

The base of SBZ13 is positioned according to Rodríguez-Pintó et al. (2022, Figs. 14–15) for the correlation with magnetostratigraphy. Benedetti et al. (2024) and Hadi et al. (2026b) correlate it within CNE8.

SBZ14

The base of SBZ14 is according to Rodríguez-Pintó et al. (2012, Fig. 8), Silva-Casal et al. (2021) and Juvany et al. (2024, Fig. 6) for the correlation with magnetostratigraphy within C20r. Payros et al (2007) and Molina et al. (2011) suggested that it corresponds to the CP13a/CP13b boundary, within E8.

SBZ15

The base of SBZ15 is tentatively proposed according to Cantalejo et al. (2020, Fig. 2) for the correlation with lowermost NP16 and C20n. Juvany et al. (2024, Fig. 6) confirmed the base within C20n. The base of SBZ15 seems to be almost coincident with the base of CNE13.

SBZ16

The base of SBZ16 is according to Rodríguez-Pintó et al. (2012, Fig. 8) and Silva-Casal et al. (2021) within C19r. Cantalejo et al. (2020, Fig. 2) put it within C19r and NP16.

SBZ17

The base of SBZ17 is still positioned according to Silva-Casal et al. (2021, Fig. 37) at the top of C19n. Cantalejo et al. (2020, Fig. 2) confirmed the base SBZ17 at the top C19n and within NP16.

SBZ18

The base of SBZ18 is positioned according to Agnini et al. (2021), along the Varignano section, which contains the Bartonian GSSP. It seems to lie in the middle of CNE15 and also in the middle part of C18n1n. It lies within CP14b and NP17 in Özcan et al. (2019).

The SBZ18b and 18c bases are after Less and Özcan (2012) and Özcan et al. (2022), with the first (base 18b) quite correctly positioned, whilst 18c base seems still uncertain. It's worth noting that SBZ18a and 18b sensu Costa et al. (2013) are different from these as they are based on other taxa.

SBZ19

The base of SBZ19 is positioned according to Cotton et al. (2017, Fig. 15), where it is correlated with nannofossils (CNE18–19) and magnetostratigraphy (C16n2n), apparently still in E14. The base of SBZ19b is obtained by combining data after Luciani et al. (2020, Fig. 2) and Less et al. (2008, Tab. 7).

SBZ20

The base of SBZ20 is here still tentatively referred to Less et al. (2008), according to correlation with planktonics and nannofossils of the species reported in their Tab. 7.

SBZ21

The base SBZ21 is obtained by comparing the dinoflagellate biozones of the Priabona section with the Rupelian GSSP (Premoli Silva and Jenkins 1993; van Mourik and Brinkhuis 2005), combined with data after Houben et al. (2012); the base of Rupelian is at the top of the dinoflagellate zone Aal; the Priabona section has SBZ20 until the biozone Adi, corresponding to the base of CP16b and Chron C13n. Note that in this new configuration, SBZ20 enters into the Oligocene and so should OZ16.

SBZ22

The base of SBZ22a is according to Hadi et al. (2023, Figs. 4–5) for the correlation with the nannofossils zone NP23; also the FO of *Eulepidina* is dated 30–31Ma according to Sr isotopes by Less et al. (2018). Note that Benedetti et al. (2018) in Illats, Aquitaine, referred to SBZ22a as dated around 28.9–30.2 Ma but without robust independent data by planktonics.

The base of SBZ22b is according to Less et al. (2018), ages obtained by Sr isotopes corrected for GTS 2020. Notice that here the Rupelian/Chatian boundary reported by Speijer et al. (2020) and as indicated by TS Creator (v.8.1; 2026) has been lowered to 27.82 Ma following Coccioni et al. (2018), who defined the Chatian GSSP.

SBZ23

The base of SBZ23 is referred to Less et al. (2018, Tab. 9) and Briguglio et al. (2021), both ages obtained by Sr isotopes. Porto Badisco, at the top of SBZ23, is dated 23.6 Ma (23.1–24 Ma)

in Parente and Less (2019), in the uppermost NP25, close to the P22/N4 boundary, thus the datum is consistent with a base of SBZ24 close to Oligocene/Miocene boundary.

SBZ24-26

For the bases of SBZ24, 25, and 26 there are no improved data. We report here the boundaries by Cahuzac and Poignant (1997). Notice that here the boundary SBZ 25/26 reported by Speijer et al. (2020) has been moved to the Burdigalian/Langhian boundary as in Cahuzac and Poignant (1997). For the Langhian we consider a straight boundary because of the recent definition of its GSSP (Turco et al. 2024).

DISCUSSION

Differences from the Previous Version

Due to the new geochronologic calibration of the 2020 GTS, there are several variations in the biostratigraphic table here proposed: they are all briefly discussed here below.

The new subdivisions from SBP1 to SBP4 proposed by Papazzoni et al. (2023) are based on different taxa from those considered when SBZ zonation was first introduced in the Paleogene by Serra-Kiel et al. (1998) and maintained in the first revision by Papazzoni et al. (2017). The FO of *Elazigina die-nii*, followed by the FO of orthophragmines marks a major step forward in this biostratigraphic chart and it is likely to be much more stable in the years to come because the bases of both SBP2 and SBP3 are strongly linked with plankton biostratigraphy and partially also with magnetostratigraphy. In this new chart, if a comparison between Paleocene SBZ and SBP has to be done, SBP1 is much shorter than SBZ1, SBP2 is much longer and the base of SBP3 is slightly younger than the previous SBZ3. The base of SBP4 is also slightly younger than the previous SBZ4 but this new boundary might be adjusted in the future if more data will be available.

SBZ5 traditionally marked the beginning of the Eocene with the first appearance of true *Alveolina* with both prae- and post-septal passages. Indeed, the genus *Alveolina* appeared within SBP4 with *A. korresensis* (Serra-Kiel et al. 2020). In this updated version we acknowledged that the SBZ5 starts just after the CIE excursion and therefore already in the Ypresian, therefore slightly after the Paleocene/Eocene boundary. Being very short, it immediately passes on SBZ6 which is similarly short. The old correlation that SBZ5 and SBZ6 correspond to E1 and E2 is mostly maintained.

In the lower Ypresian, SBZ7 was much longer in Papazzoni et al. (2017), but here it goes back to almost its initial size as proposed by Serra-Kiel et al. (1998). Hottinger (2001; 2014) noted that SBZ9 is underrepresented in the fossil record due to the insufficient preservation of sedimentary deposits suitable for K-strategist foraminifera. SBZ9 is now the shortest biozone but maintains almost the same boundary to SBZ10 as in Papazzoni et al. (2017); however, in relation to nannofossils stratigraphy some major changes happened: in the previous versions, the base of SBZ9 was almost coincident with the base of NP12, whereas with this time scale, it is the SBZ10 base which is very close to the base of NP12.

The following biozone in the upper Ypresian, namely SBZ11, was already well-calibrated with magnetostratigraphy in the previous version and in this update has not significantly changed. The uncertainty proposed for the base of SBZ12 in the previous version is here deleted because new correlation with magnetostratigraphy adjusted the boundary almost to the same interval as

proposed firstly by Serra-Kiel et al. (1998). Nonetheless, SBZ12 now crosses the Ypresian/Lutetian boundary and does not end, as previously considered, at the boundary itself (e.g., Benedetti et al. 2024). SBZ13 has become significantly shorter and whilst it previously ended at the P9/P10 boundary, now it is completely enclosed within the middle part of P9 and the base of SBZ14 has become relatively older, corresponding now to the CNE9 - CNE10 boundary, just above the base of E8.

The base of SBZ15 had previously a largely uncertain definition; now it is correlated with better definition with the geomagnetic scale and the plankton stratigraphy and became quite similar to its first position in Serra-Kiel et al. (1998). The short SBZ16 remained still short but it is now slightly older, in the uppermost part of the Lutetian, with the base of SBZ17 positioned tentatively at the base of the Bartonian, which was in Papazzoni et al. (2017) located at the base of SBZ16.

With this new GTS2020 and the definition of the Priabonian GSSP, the Bartonian became slightly longer and so became SBZ17, which is, in this new chart, very similar to the one reported in Serra-Kiel et al. (1998). However, due to the changes in geochronology, the new SBZ17 ends in the middle part of E13, whilst according to Papazzoni et al. (2017) it ended slightly higher, almost at the P14/P15 boundary. The Bartonian/Priabonian boundary is crossed by SBZ18, which keeps its subdivision into three subzones that are not yet calibrated to any other independent proxy. The new base of SBZ19 remained similar in relation to the plankton stratigraphy (top of E14) but its absolute age became younger starting at 36.0 Ma instead of 36.5 Ma as previously indicated. This new chart provides a correlation of the base of SBZ19 to the lowermost part of CNE19.

The last biozone of the Eocene, always considered to end at the Eocene/Oligocene boundary, is here proposed to extend into the lowermost Oligocene according to recent data about the GSSP position (van Mourik and Brinkhuis 2005; Houben et al. 2012), because the base of SBZ21 is here proposed to be almost at the boundary between C13n and C12r, slightly after the base of CP16b.

The entire SBZ22a is tentatively related to the entire C11, according to the newly published data and therefore is slightly older than previously considered.

The base of SBZ22b is significantly lower than the previous one, even though the Rupelian/Chattian boundary has also been lowered according to the new GSSP of the Chattian. Anyway, the base of SBZ22b is no longer coincident with the Rupelian/Chattian boundary.

The base of SBZ23 does not seem to include CP19 or O5 anymore and is therefore tentatively located just underneath those biozones.

The biozones from SBZ24 to SBZ26 are still placed where they were proposed in the previous versions and are basically correlated to the chronostratigraphic stages due to lack of integrated biostratigraphic data.

CONCLUSIONS

The original Tethyan Shallow Benthic Zonation (SBZ) of Serra-Kiel et al. (1998) and Cahuzac and Poignant (1997) was a monumental achievement, providing a necessary framework

for shallow-water Cenozoic stratigraphy. Here we propose an updated and more calibrated and chronologically accurate biostratigraphic scheme, based on the most recent integrated data from nannofossils, planktonic foraminifera, and magnetostratigraphy. The most significant step has been the adoption of the biohorizon concept (as seen in the SBP zones for the Paleocene, see Papazzoni et al. 2023), which minimizes the ambiguity of assemblage-based boundaries. This is currently not applied to the subsequent biozones and should be the object of new definitions in future, to achieve a new system of biozonation for the Eocene, Oligocene, and Miocene.

This revision contributes to the expansion of SBZs toward a globally precise geochronological correlation standard for shallow marine environments. However, this has to face the difficulty to find shallow-water bioevents coeval in the whole Neotethys because of the occurrence of endemism and diachronous distribution of some taxa especially in the easternmost Tethys (e.g., Benedetti and Papazzoni 2022).

A formal revision for the Oligocene–Miocene SBZs is still pending. Major issues remain: i) direct correlations between LF and planktonic foraminifera or nannofossil zones are rare in most Tethyan shallow-water sections; ii) the Oligocene–Miocene saw the development of strong provincialism between the Western Tethys (Mediterranean) and the Indo-Pacific LF faunas; iii) Oligocene–Miocene climatic events, such as the Icehouse evolution of the Earth, the Late Oligocene Warming Event (LOWE), and the Middle Miocene Climatic Optimum (MMCO) significantly impacted LF diversity and distribution.

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