Biostratigraphy of the Estepona assemblages (southern Spain), based on calcareous nannofossils and planktonic foraminifera

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Received 7 April 2025, revised version accepted 10 April 2025.

Marine sedimentary deposits of the Velerín area (Malaga province, southern Spain) contain the Estepona mollusc assemblages. While a Pliocene age is generally accepted, the exact stratigraphic position is subject of ongoing discussions. Here, we present new biostratigraphic data from calcareous nannofossils and planktonic foraminifera. Biostratigraphic marker species suggest a correlation of the Estepona assemblages with late Zanclean biozones MNN14/NN15/CNPL3 (calcareous nannofossils) and MPl4a/late PL2 to PL3 (planktonic foraminifera), corresponding to an age of c. 4.0-3.8 Ma.

Key words: Estepona, Spain, biostratigraphy, age, late Zanclean

Introduction

Description of the exceptionally rich gastropod fauna from the Estepona assemblages has been an ongoing research project for co-authors (B.L., M.H.; *inter alia*) of this study for the last 20 years. These studies focus on the area of Velerín, located in the Malaga province of southern Spain, some 5 km north-east of the town of Estepona, on the left bank of the Rio del Castor, 1.2 km away from the present-day Mediterranean Alborán Sea coast (geographical coordinates: 36.45033°N, -5.097431°E; Fig. 1).
The Pliocene deposits in the Velerín site area consist of one exposure of around 6 m of channelised conglomerate beds intercalated with sandy and coarse sandy lenses up to 1 m thick. The very coarse conglomerates are mostly made of clasts of metamorphic rocks around 3 to 10 cm in diameter originating from the Sierra Bermeja substrate, but larger blocks up to 0.5 m also occur. The total thickness of these conglomerates is unknown. Another, topographically lower exposure (location Velerín carretera) consists of marly clays, sometimes with sandy intercalations, a quite different facies from the coarse facies unit described above. Yet another facies unit, topographically above the coarse facies, consists of a reasonably well-sorted coarse sand (El Lobillo). The age relationships between the various facies units are poorly known.
Fossils of invertebrate animals, mostly molluscs, are abundant in these deposits, be it in clays, sands and conglomerates. According to Aguirre (1995) and Aguirre *et al.* (2005), the Estepona Basin deposits represent one single transgressive unit. However, Guerra-Merchán *et al.* (2002) considered three units for these deposits in the Estepona–San Pedro de Alcántara area, with the Velerín sequence corresponding to the upper part of the lower conglomeratic section of their 'middle Pliocene unit' deposited – after Aguirre *et al.* (2005) – in a marine inner fan-delta environment.
Although regarded as Pliocene since the very first studies (*e.g.*, Ansted, 1857), there has been controversy surrounding the precise stratigraphic position of the rich molluscan fossiliferous assemblages of the Estepona Basin, namely those of the Velerín area. Since the late nineteenth century, these deposits have been assigned to the 'middle to upper Pliocene' (*e.g.*, Bertrand & Kilian, 1892; González-Donoso & de Porta, 1977). In the early twenty-first century, based on planktonic foraminifera, Guerra-Merchán *et al.* (2002) assigned the 'middle Pliocene unit' to biozones MPl4b to MPl5a of Cita (1975), *i.e.*, to the lower Piacenz-

Figure 1. Geographic map showing the study area Estepona-Velerín in the Malaga region of southern Spain. Topographical locations of sites mentioned in this paper are generally indicated, situated just west of their respective names. Satellite image and version courtesy Google Earth, April 2023.

ian (lower Upper Pliocene). Later, based on the assemblage of planktonic heteropod and pteropod gastropods, Janssen (2004), again, correlated these deposits with the lower Piacenzian, although for some sites of the Velerín area − where the holoplanktonic gastropod assemblage was poorer − a Zanclean (Early Pliocene) age could not be excluded. Despite the extreme paucity of calcareous nannofossils, resulting from a shallow depositional setting and perhaps selective removal due to chemical weathering by percolating groundwater (Janssen, 2004), Aguirre *et al.* (2005) tentatively assigned the Velerín fossil assemblage to calcareous nannofossil biozone CN11b of Okada & Bukry (1980), *i.e.*, to the latest Zanclean (latest Early Pliocene). For more information on the general geological setting and the stratigraphy of the Estepona Basin and the Velerín area in particular see Guerra-Merchán *et al.* (2002) and Aguirre *et al.* (2005).

In order to re-evaluate the age of these assemblages, fresh samples were taken for the present study and processed at the Geosphere Austria (calcareous nannoplankton) and in the Natural History Museum Vienna (NHMW) (Foraminifera), where the gastropod collections reviewed by our team are housed.

Material and methods

Calcareous nannofossils (Plate 1)

Calcareous nannofossils were studied from four samples: Velerín carretera (sample 1), Parque Antena (sample 2), Velerín conglomerates (sample 3) and El Lobillo (sample 4). Smear slides were prepared for all samples using standard procedures described by Perch-Nielsen (1985). All samples were examined with a DMLP Leica light microscope (crossed and parallel nicols) with 1000x magnification. The following biostratigraphic concepts were applied: the MNN biozonation for the Mediterranean by Di Stefano *et al.* (2023); the standard NN biozonation by Martini (1971); and the CNPL biozonation for low and middle latitudes by Backman *et al.* (2012).

Planktonic foraminifera (Plate 2)

Planktonic foraminifera were studied from the Velerín carretera (sample 1) and Parque Antena (sample 2) sites. The Velerín conglomerates (sample 3) and El Lobillo (sample 4) samples were barren of planktonic foraminifera. Bulk sediment was treated with H_2O_2 and washed through sieves with a minimum mesh-size of 63 µm. At least 200 specimens were picked from the residues of size fractions > 125 µm. Biostratigraphic markers in the assemblages were identified and documented with a Zeiss Discovery V20 microscope.

Due to the location of the studied sections in proximity to the Gibraltar Strait, the most recent revision of the Mediterranean biozonation presented by Lirer *et al.* (2019) as well as the Atlantic biozonation of Raffi *et al.* (2020) with the addition of the datum for the temporary disappearance of *Globorotalia puncticulata* (Sierro *et al.*, 2009), corresponding to LO of *G. puncticulata* in the Mediterranean (Lirer *et al.*, 2019), were considered.

Taxonomic concepts followed Lirer *et al.* (2019) with a focus on globorotaliid species, the sole group of planktonic foraminifera providing useful biostratigraphic markers in the studied samples. Mediterranean biostratigraphy of the Pliocene largely relies on the evolutionary lineage of *Globorotalia puncticulata* and its descendant *G. bononiensis* (Lirer *et al*., 2019). *G. puncticulata* shows considerable morphological variability with a range of transitional forms to *G. bononiensis* closer to the later species' first occurrence (Iaccarino, 1985; Bossio *et al*., 1997; Lirer *et al*., 2019). Transitional morphotypes are herein referred to as *G. puncticulata* s.l.

Abbreviations: FCO = first common occurrence; FO = first occurrence; LO = last occurrence; LCO = last common occurrence.

Results

All samples contain well-preserved calcareous nannofossils and rare ascidian spicules (Pl. 1). Richest assemblages occur in samples from Velerín carretera (sample 1) and Parque Antena (sample 2). They are dominated by *Reticulofenestra minuta* accompanied by the following species: *Braarudosphaera bigelowii*, *Calcidiscus leptoporus*, *C. macintyrei*, *Ceratolithus* sp., *Coccolithus pelagicus*, *Discoaster brouweri*, *D. exilis*, *D. surculus*, *D. tamalis*, *Gephyrocapsa* sp. small (<3.5µm), *Helicosphaera carteri*, *H. sellii*, *Pontosphaera discopora*, *P. japonica*, *P. multipora*, *P. syracusana*, *Pseudoemiliania lacunosa*, *Reticulofenestra haqii*, *R. pseudoumbilicus*, *Rhabdosphaera clavigera*, *Scyphosphaera globulata*, *S. globulosa*, *S. lagena*, *S. ventriosa*, *Sphenolithus abies*, *Sphenolithus moriformis*, *Syracosphaera mediterranea*, *Umbilicosphaera jafari*, *U. rotula*.

The sample from the Velerín conglomerates (sample 3) is characterised by very rare calcareous nannofossils with *Calcidiscus leptoporus*, *Coccolithus pelagicus*, *Gephyrocapsa* sp. small (<3.5µm), *Helicosphaera sellii*, *Reticulofenestra haqii*, *Reticulofenestra minuta* and *Reticulofenestra pseudoumbilicus*.

The sample from El Lobillo (sample 4) contains rare nannofossils with *Calcidiscus leptoporus*, *Coccolithus pelagicus*, *Gephyrocapsa* sp. small (<3.5µm), *Reticulofenestra minuta*, *Reticulofenestra producta*, *Reticulofenestra pseudoumbilicus* and *Sphenolithus abies*.

Rare reworking from the Upper Cretaceous (*Micula staurophora*, *Watznaueria barnesiae*) and Eocene/Oligocene (*Coccolithus formosus*, *Reticulofenestra bisecta*) was documented in all samples.

Samples from Velerín carretera (sample 1) and Parque Antena (sample 2) contain rich and distinct assemblages of planktonic foraminifera. Globorotaliids are rare (< 5% of the assemblage) at Velerín carretera and show a considerable range of morphological variability. A few specimens of *Globorotalia puncticulata* and *G. puncticulata* s.l. as well as a single specimen of *G. crassaformis* occur (Pl. 2, figs 4–15). At Parque Antena, globorotaliids are more common (> 10%) and represented solely by *G. puncticulata* (Pl. 2, figs 1–3).

Discussion

Based on the calcareous nannofossil assemblages, all samples can be attributed to biozone NN15 (Fig. 2; Martini, 1971). This biozone is defined as the interval between the last occurrences of *Amaurolithus tricorniculatus* (LO 3.93 Ma, LO_{Med} 4.55 Ma) and *R. pseudoumbilicus*

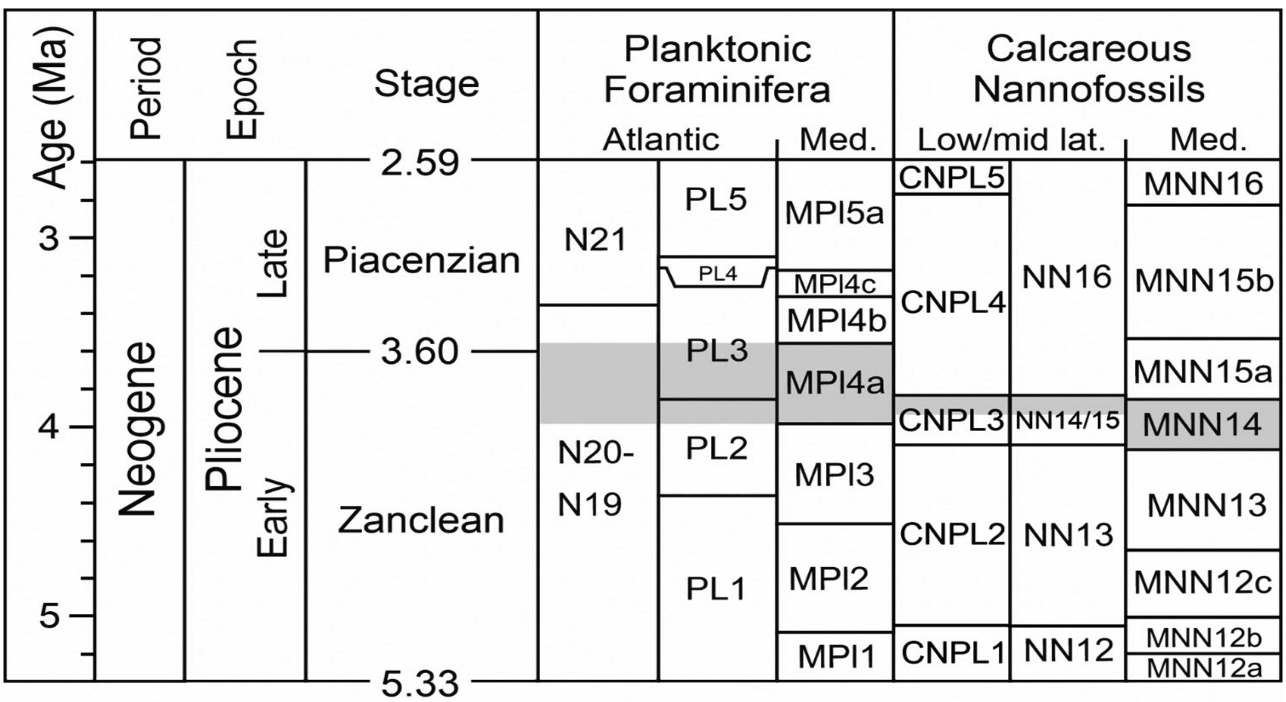

Figure 2. Stratigraphic table. Biozones for planktonic foraminifera and calcareous nannofossils compiled from Lirer *et al.* (2019), Gradstein *et al.* (2020), and Di Stefano *et al.* (2023). Stratigraphic ranges inferred from planktonic foraminifera and calcareous nannofossils for the herein studied samples from Estepona are highlighted in grey.

(LO 3.82 Ma). Backman *et al*. (2012) merged zones NN14 and NN15 into zone CNPL3 and defined it as the interval between first common occurrence *Discoaster asymmetricus* (FCO 4.04 Ma) and the LO of *R. pseudoumbilicus*. This biozone also contains the FO of *Pseudoemiliania lacunosa*. In the Mediterranean, the samples are correlated with biozone MNN14, defined as the interval between the FCO of *D. asymmetricus* (FCO_{Med} 4.11 Ma) and the LO of *R. pseudoumbilicus* (LO_{Med} 3.85 Ma; Di Stefano *et al*., 2023). These species are present in samples 1 and 2. Biozones CNPL3 (NN15) and MNN14 correspond to the latest Zanclean (Backman *et al*., 2012; Raffi *et al*., 2020; Di Stefano *et al*., 2023). A correlation to the late Zanclean is further supported by occurrences of *Sphenolithus moriformis* and *S. abies* in samples 1, 2 and 4 (LO *Sphenolithus* spp. 3.61 Ma, LO_{Med} 3.73 Ma; Backman *et al*., 2012; Di Stefano *et al*., 2023), *Scyphosphaera ventricosa in* sample 1 (LO at the top of NN15 and CNPL3; Young, 1998), and *Discoster tamalis* in samples 1 and 2 (NN14 to NN16, CNPL3 to CNPL4, and MNN14 to MNN15; Raffi *et al*., 2006; Young, 1998).

The correlation with late Zanclean calcareous nannofossil biozones NN15, CPL3, and MNN14 are in agreement with Aguirre *et al*. (2005) who correlated the Velerín sequence to biozone CN11b of Okada & Bukry (1980), corresponding to biozones NN14/15 and CNPL3 (Backman *et al*., 2012).

Concerning planktonic foraminifera, the presence of *G. puncticulata* ($LO_{Med+Atl}$ 3.57 Ma) and the absence of *G. margaritae* (LCO_{Med} 3.98 Ma, LO_{Med} 3.81 Ma, LO_{Atl} 3.85 Ma) suggests a correlation of both samples with late Zanclean to earliest Piacenzian Mediterranean sub-biozone MPl4a (3.98–3.57 Ma; Lirer et *al*., 2019) and Atlantic biozones upper PL2 to lower PL3 (3.85–3.57 Ma; Sierro *et al.,* 2009; Gradstein *et al.,* 2020) (Fig. 2).

Based on the morphological variability of *G. puncticulata* and the occurrences/non-occurrences of other globorotaliid taxa, a correlation to distinct Mediterranean biohorizons within biozone MPl4a may be considered. For the sample from Velerín carretera, the very rare occurrence of *G. crassaformis* specimens (FO_{Med} 3.6 Ma) alongside *G. puncticulata* s.l., representing a range of transitional forms to *G. bononiensis* (FO_{Med} 3.59 Ma), may suggest an age close to the end of the Zanclean (Lirer *et al*., 2019). In contrast, the absences of *G. crassaformis* and *G. puncticulata* s.l. at Parque Antena may indicate

Plate 1. Calcareous nannofossils from the studied sites

1-2 *Coccolithus pelagicus* (Wallich, 1877) Schiller, 1930, Velerín carretera.
3 *Coccolithus pelagicus* cf. subsp. *braarudii* (Gaarder, 1962) Geisen et al., 2002, Velerín carretera.
4 *Reticulofenestra pseudoumbilicus* (Gartner, 1967) Gartner, 1969, Velerín carretera.
5 *Reticulofenestra haqii* Backman, 1978, Parque Antena.
6 *Reticulofenestra minuta* Roth, 1970, Velerín carretera.
7 *Gephyrocapsa* small, Velerín conglomerate.
8 *Reticulofenestra pseudoumbilicus* (Gartner, 1967) Gartner, 1969, Parque Antena.
9 *Reticulofenestra haqii* Backman, 1978, Velerín carretera.
10 *Reticulofenestra minuta* Roth, 1970, Parque Antena.
11 *Syracosphaera pulchra* Lohmann, 1902, Velerín carretera.
12-13 *Umbilicosphaera rotula* (Kamptner, 1956) Varol, 1982, Velerín carretera.
14-15 *Helicosphaera sellii* (Bukry & Bramlette, 1969) Jafar & Martini, 1975, Velerín carretera.
16-17 *Helicosphaera carteri* (Wallich, 1877) Kamptner, 1954, Velerín carretera.
18 *Helicosphaera wallichii* (Lohmann, 1902) Okada & McIntyre, 1977, Velerín carretera.
19-20 *Pontosphaera japonica* (Takayama, 1967) Nishida, 1971, Velerín carretera.
21 *Syracosphaera mediterranea* Lohmann, 1902, Velerín carretera.
22-23 *Pontosphaera multipora* (Kamptner, 1948 ex Deflandre in Deflandre & Fert, 1954) Roth, 1970, Velerín carretera.
24 *Sphenolithus abies* Deflandre in Deflandre & Fert, 1954, Parque Antena.
25 *Sphenolithus moriformis* (Brönnimann & Stradner, 1960) Bramlette & Wilcoxon, 1967, Parque Antena.
26-27 *Calcidiscus leptoporus* (Murray & Blackman, 1898) Loeblich & Tappan, 1978, Velerín carretera.
29-30 *Calcidiscus macintyrei* (Bukry & Bramlette, 1969) Loeblich & Tappan, 1978, Velerín carretera.
31 *Pontosphaera discopora* Schiller, 1925, Velerín carretera.
32 *Discoaster brouweri* Tan Sin Hok, 1927, emend. Bramlette & Riedel, 1954, Velerín carretera.
33 *Discoaster tamalis* Kamptner, 1967, Velerín carretera.
34 *Discoaster asymmetricus* Gartner, 1969, Velerín carretera.
35 *Discoaster pentaradiatus* Tan Sin Hok, 1927, Velerín carretera.
36-37 *Rhabdosphaera clavigera* Murray & Blackman, 1898, Velerín carretera.
38-39 *Braarudosphaera bigelowii* (Gran & Braarud, 1935) Deflandre, 1947, Velerín carretera.
40-41 Ascidian spicules, Velerín carretera.
42 *Scyphosphaera ventriosa* Martini, 1968, Velerín carretera.
43-44 *Scyphosphaera rottiensis* Jafar, 1975, Velerín carretera.
45-46 *Scyphosphaera* cf. *apsteinii* Lohmann, 1902, Velerín carretera.
47-48 *Scyphosphaera globulosa* Kamptner, 1955, Velerín carretera.

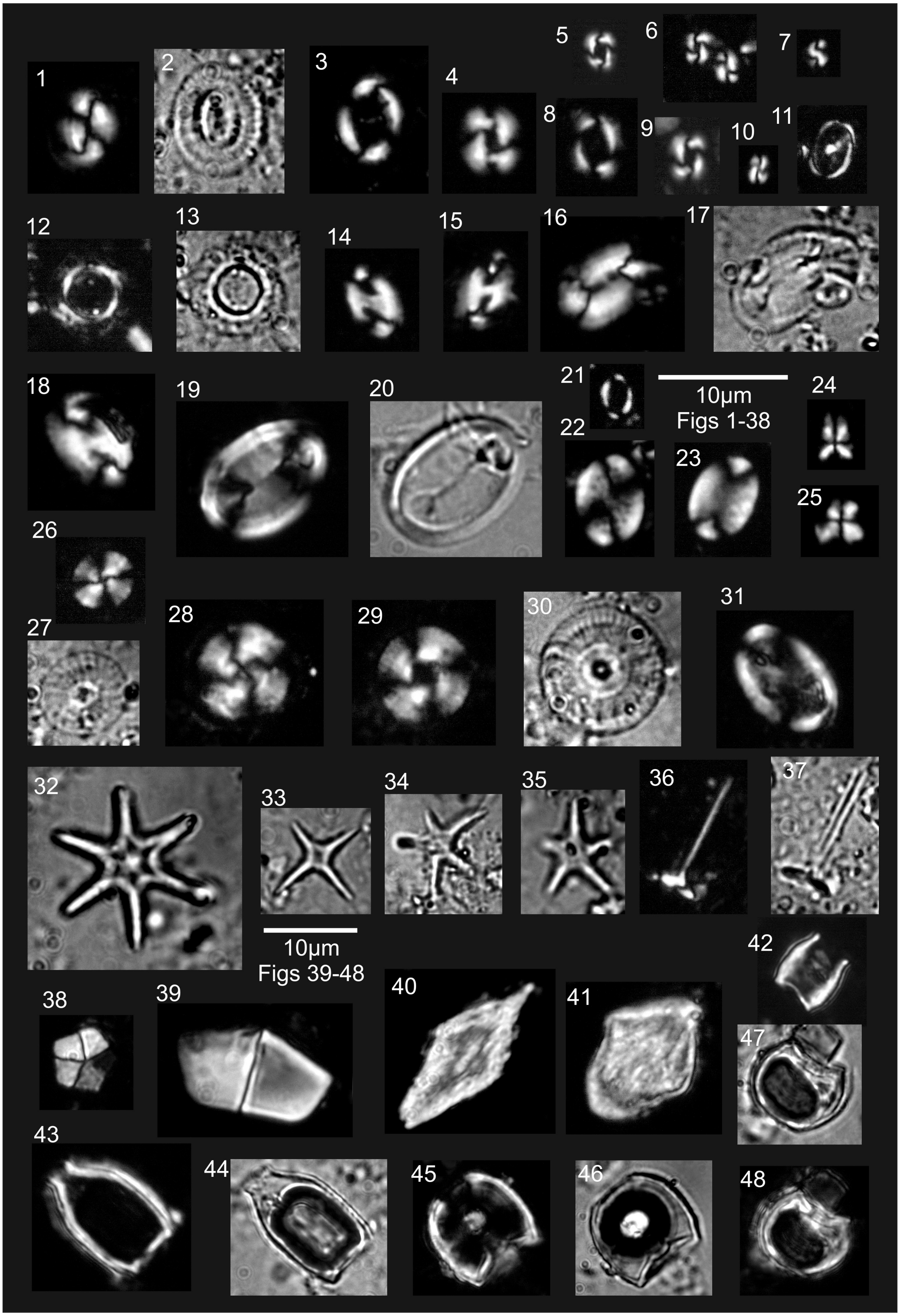
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Plate 1

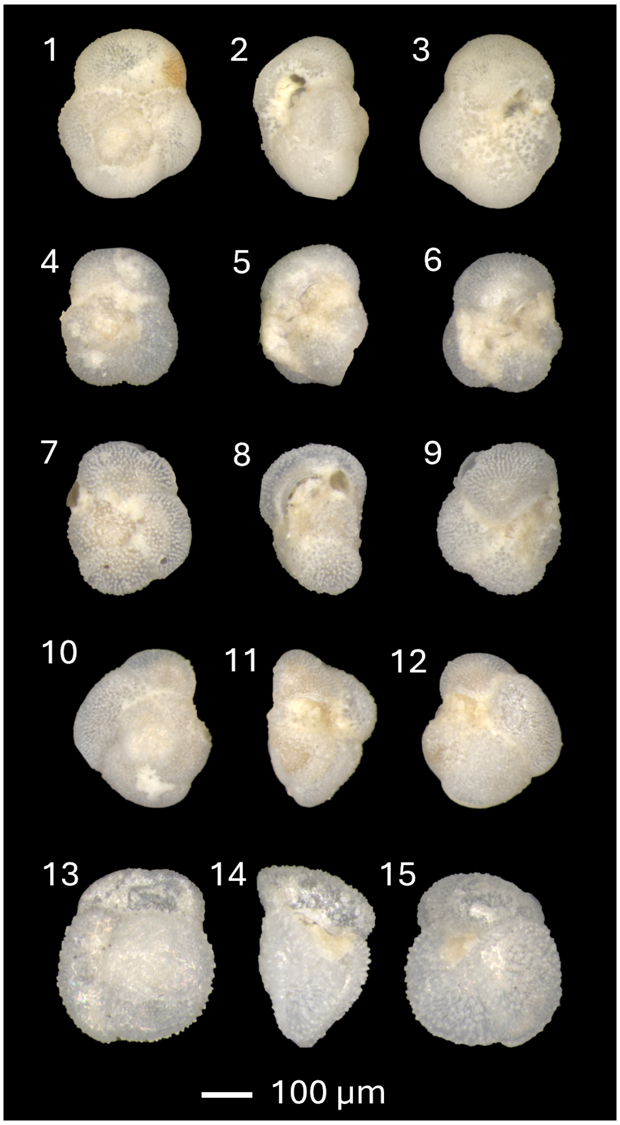

Plate 2. Planktonic foraminifera used as biostratigraphic markers in this study. 1-3. *Globorotalia puncticulata* (Deshayes, 1832), Parque Antena; 4-6. *Globorotalia puncticulata* (Deshayes, 1832), Velerín carretera; 7-9. *Globorotalia puncticulata* s.l., Velerín carretera; 10-12. *Globorotalia puncticulata* s.l., Velerín carretera; 13-15. *Globorotalia crassaformis* (Galloway & Wissler, 1927), Velerín carretera.

a slightly older, late Zanclean age for the sample, correlating with the earlier portion of sub-biozone MPl4a (3.81–3.6 Ma; Lirer *et al.*, 2019). However, this interpretation may have to be taken with caution. Aguirre et al. (2005) have described co-occurrences of *G. margaritae* and *G. crassaformis* (FO_{Med} 3.6 Ma, FO_{Atl} 4.31 Ma) from the Estepona sites, suggesting temporary, geographically restricted influxes of *G. crassaformis* from the North Atlantic to the westernmost Mediterranean in proximity to the Gibraltar Strait, prior to its FO at the biostratigraphic reference sections in the central Mediterranean.

Planktonic foraminifera have previously been reported from the study area by Guerra-Marchan *et al.* (2002). Based on occurrences of *G. puncticulata*, *G. crassaformis*, *G. bononiensis* and *G. aemiliana*, a correlation of samples from Velerín carretera and Parque Antena with Piacenzian sub-biozones MPl4b to MPl5a of Cita (1975) was proposed. Samples showing the sole occurrence of *G. puncticulata* amongst globorotaliids, such as in the sample from Parque Antena of this study, were not reported by Guerra-Marchan *et al.* (2002). Instead, they suggested a hiatus spanning the late Zanclean and early Piacenzian (MPL3 to MPL4a of Cita, 1975). The obvious discrepancy in the biostratigraphic interpretation between this and the present study is striking. This may at least partially be attributed to different species concepts, in particular with respect to the morphological variability in *G. puncticulata*. However, a meaningful assessment of the underlying reasons is prevented by the lack of information on species concepts and representative images of the biostratigraphic marker species in Guerra-Marchan *et al.* (2002).

While the reconciliation of Guerra-Marchan *et al.* (2002) and the present study is challenging, a correlation with the late Zanclean for the herein studied samples is well in line with integrated data from calcareous nannofossils and planktonic foraminiferal assemblages presented by Aguirre *et al.* (2005). It is noteworthy, however, that contrary to the present study *Globorotalia margaritae* was recorded in some samples from Velerín carretera and Parque Antena, suggesting a slightly older late Zanclean age, yet within the range of calcareous nannofossil biozones MNN14, NN14/15, and CNPL3 (corresponding to CN11b in Aguirre *et al.*, 2005).

In summary, our new microfossil data lend strong support to a late Zanclean age between c. 4.0 and 3.8 Ma for the Estepona mollusc assemblages.

Conclusion

The evaluation of calcareous nannofossils and planktonic foraminifera from the Velerín sequence suggests a correlation with the late Zanclean. Based on the co-occurrences of *R. pseudoumbilicus*, *D. tamalis* and *P. lacunosa* and the absence of *A. tricorniculatus* all investigated samples can be attributed to the calcareous nannoplankton biozones MNN14, NN15, and CNPL3, which corresponds to an age of 4.04 to 3.82 Ma. The occurrence of *Globorotalia puncticulata* and absence of *Globorotalia margaritae* and *G. bononiensis* suggests a correlation to planktonic foraminifera sub-biozone MPl4a and upper biozone PL3 to lower PL4, indicating a maximum age range of 3.98 to 3.57 Ma. The combined stratigraphic range of c. 4.0-3.8 Ma corroborates previous microfossil studies and lends strong support to a late Zanclean age for the Estepona mollusc assemblages.

Acknowledgements

Gerit Griesmeier (GeoSphere Austria, Vienna) is thanked for her help with preparing the calcareous nannofossil plate. Gerald Auer (University of Graz) is acknowledged for providing P.G. access to a microscope.

References

Aguirre, J. 1995. *Tafonomía y evolución sedimentaria del Plioceno marino en el litoral sur de España entre Cádiz y Almería*. Granada (University of Granada): pp. 1-419 (*Ph.D. thesis*).

Aguirre, J., Cachão, M., Domènech, R., Lozano-Francisco, C., Martinell, J., Mayoral, E., Santos, A., Vera-Pelaez, J.L. & Silva, C.M. da 2005. Integrated biochronology of the Pliocene deposits of the Estepona Basin (Málaga, S Spain). Palaeobiogeographic and Palaeoceanographic implications. *Revista Española de Paleontología* 20(2): 225-244.

Ansted, D.T. 1857. On the geology of Malaga and the southern part of Andalucía. *Quarterly Journal of the Geological Society* 15: 585-604.

Backman, J., Raffi, I., Rio, D., Fornaciari, E. & Pälike, H. 2012. Biozonation and biochronology of Miocene through Pleistocene calcareous nannofossils from low and middle latitudes. *Newsletters on Stratigraphy* 45(3): 221-244.

Bertrand, M. & Kilian, M. 1892. Estudio de los terrenos Secundarios y Terciarios de las provincias de Granada y Málaga. *Boletín de la Comisión del Mapa Geológico de España* 18: 257-447.

Bossio, A., Foresi, L.M., Mazzanti, R., Mazzei, R., Salvatorini, G. & Squarci, P. 1997. Note micropaleontologiche sulla successione miocenica del Torrente Morra e su quella pliocenica dei Fiumi Tora e Fine (Provincie di Livorno e Pisa). *Atti della Società Toscana di Scienze Naturali. Memorie Serie A* 104: 85-134.

Cita, M.B. 1975. Studi sul Pliocene e gli strati di passaggio dal Miocene al Pliocene. VII. Planktonic foraminiferal zonation of the Mediterranean Pliocene deep sea record. *Rivista Italiana di Paleontologia e Stratigrafia* 81: 527-544.

Di Stefano, A., Baldassini, N., Raffi, I., Fornaciari, E., Incarbona, A., Negri, A., Bonomo, S., Villa, G., Di Stefano, E. & Rio, D. 2023. Neogene Quaternary Mediterranean calcareous nannofossil biozonation and biochronology: a review. *Stratigraphy* 20: 259-302.

González-Donoso, J.M. & de Porta, J. 1977. Datos preli minares sobre un afloramiento de materiales pliocénicos en Estepona (provincia de Málaga). *Studia Geológica Salmanticensia* 13: 31-57.

Guerra-Merchán, A., Serrano, A. & Ramallo, D. 2002. Evolución sedimentaria y paleogeográfica pliocena del borde septentrional de la cuenca de Alborán en el area de Estepona (provincia de Málaga, Cordillera Bética). *Pliocénica* 2: 31-43.

Iaccarino, S. 1985. Mediterranean Miocene and Pliocene planktic foraminifera. *In*: Bolli, H.M., Saunders, J.B. & Perch-Nielsen, K. (eds.). *Plankton Stratigraphy*. Cambridge (Cambridge University Press): 283-314.

Janssen, A.W. 2004. Holoplanktonic molluscan assemblages (Gastropoda, Heteropoda, Thecosomata) from the Pliocene of Estepona (Spain, Malaga). *Palaeontos* 5: 103-131.

Lirer, F., Foresi, L.M., Iaccarino, S.M., Salvatorini, G., Turco, E., Cosentino, C., Sierro, F.J. & Caruso, A. 2019. Mediterranean Neogene planktonic foraminifer biozonation and biochronology. *Earth-Science Reviews* 196: 102869.

Martini, E. 1971. Standard Tertiary and Quaternary calcareous nannoplankton zonation. *Proceedings of the II Planktonic Conference. Ed. Tecnoscienza*, Roma: 739-785.

Okada, H. & Bukry, D. 1980. Supplementary modification and introduction of code numbers to the low-latitude coccolith biostratigraphic zonation (Bukry, 1973: 1975). *Marine Micropaleontology* 5(3): 321-325.

Perch-Nielsen, K. 1985. Cenozoic calcareous nannofossils. *In*: Bolli, H.M., Saunders, J.B. & Perch-Nielsen, K. (eds.), *Plankton stratigraphy.* Cambridge (Cambridge University Press): 427-554.

Raffi, I., Backman, J., Fornaciari, E., Pälike, H., Rio, D., Lourens, L. & Hilgen, F. 2006. A review of calcareous nannofossil astrobiochronology encompassing the past 25 million years. *Quaternary Science Reviews* 25: 3113-3137.

Raffi, I., Wade, B.S., Pälike, H., Beu, A.G., Cooper, R., Crundwell, M.P., Krijgsman, W., Moore, T., Raine, I., Sardella, R. & Vernyhorova, Y.V. 2020. The Neogene Period. *In:* Gradstein, F.M., Ogg, J.G., Schmitz, M.D. & Ogg, G.M. (eds.). *Geologic Time Scale 2020*. Amsterdam (Elsevier): 1141-1215.

Sierro, F.J., Hernandez-Almeida, I., Alonso-Garcia, M., & Flores, J.A. 2009. Data Report: Pliocene-Pleistocene planktonic foraminifera bioevents at IODP Site U1313. *In*: Channell, J.E.T., Kanamatsu, T., Sato, T., Stein, R., Alvarez Zarikian, C.A., Malone, M.J., & the Expedition 303/306 Scientists. *Proceedings of the Integrated Ocean Drilling Program, Volume 303/306*. Texas (The International Ocean Discovery Program): doi:10.2204/iodp.proc.303306.205.2009.

Young, J.R. 1998. Neogene. *In*: Bown, P.R. (ed.). Calcareous Nannofossil Biostratigraphy. *British Micropalaeontological Society Publication Series*: 225-265.