A larger benthic foraminiferal zonation
for the Cenozoic of the Americas

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Abstract: The Cenozoic of the Americas does not have a zonation based on Larger Benthic Foraminifera (LBF) unlike the Tethys where there is a shallow-water benthic zonation. Although there were faunal exchanges, the different evolutionary patterns between the Americas and the Tethys require separate zonations. We have calibrated LBF, stratigraphic distributions and events in the Americas using calcareous nannoflora (Paleocene-Eocene), planktic foraminifers (Oligocene-Miocene) and published strontium (Sr) isotope values. We define 29 zones spanning the Paleocene to Recent based on changing LBF assemblages and evolving lineages, with some zonal boundaries related to global or local palaeoenvironmental events. This will allow correlation across carbonate platforms in the tropical Americas at a higher resolution than previously possible.

Keywords:

• Cenozoic;
• Larger Benthic Foraminifera;
• biostratigraphy;
• zonation;
• Americas

Résumé : ***Zonation du Cénozoïque des Amériques à l'aide des foraminifères benthiques de grande taille.-*** Contrairement au domaine téthysien où, pour la zone néritique au cours du Cénozoïque, les biostratigraphes disposent déjà d'une zonation basée sur les foraminifères benthiques de grande taille (FBGT), il n'en existait pas encore pour les Amériques. Bien qu'il y ait eu des échanges entre les Amériques et la Téthys, les différents schémas évolutifs nécessitent des zonations distinctes. Nous avons calibré les distributions stratigraphiques des FBGT avec des événements dans les Amériques en utilisant le nannoplancton calcaire (Paléocène-Éocène) et les foraminifères planctoniques (Oligocène-Miocène), ainsi que les valeurs publiées des isotopes du strontium (Sr). Nous définissons ainsi 29 zones s'étendant du Paléocène à l'époque actuelle, basées sur les lignées évolutives et les assemblages changeants des FBGT, avec quelques limites de biozones liées à des événements paléoenvironnementaux globaux ou locaux. Ceci devrait permettre des corrélations de meilleure résolution qu'auparavant entre les plates-formes carbonatées des Amériques tropicales.

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1. Introduction

The Paleogene to early Neogene of Tethys and the western Pacific can be zoned in detail using assemblages of larger benthic foraminifers (LBF) (ADAMS, 1970; CAHUZAC & POIGNANT, 1997; SERRA-KIEL *et al.*, 1998; LESS & ÖZCAN, 2012; PAPAZZONI *et al.*, 2017, 2023). Although some zonations (often for part of the Paleogene) have been proposed for the Americas (*e.g.*, ROBINSON, 1977, 2004; BUTTERLIN, 1981; ROBINSON & JIANG, 1995; ROBINSON & MITCHELL, 1999; MITCHELL *et al.*, 2022; SIERRA *et al.*, 2023; MELLO e SOUSA *et al.*, 2023), there is no high-resolution scheme for the Cenozoic. LBF show significant palaeogeographical differences between the Americas and the Tethys, and the scheme for the Tethys cannot be used in the Americas. To address this, we have collected free specimens of LBF and investigated them using orientated equatorial and axial sections supplemented by data from the literature (CT scans are also extremely valuable: *cf.* SIERRA *et al.*, 2023). This allows the identification of critical features that allows us to develop a high-resolution zonation (Fig. 1) that cannot be achieved using random sections in rock. The zonation is calibrated against the chronostratigraphy using the NP zonation based on calcareous nannofossils (MARTINI, 1971; VANDENBERGHE *et al.*, 2012; SPEIJER *et al.*, 2020) for the Paleocene-Eocene and the P and N zonation based on planktic foraminifers for the Oligocene and Miocene (KING *et al.*, 2020). We have revised the classification of many of the forms from the Eocene of Jamaica (MITCHELL *et al.*, 2022) and use this revised taxonomy and other works to erect a series of zones (based on first and last appearances of taxa) for the Paleocene to the Recent.

American shelf-edge taxa have been chosen for the zonation because they are widely distributed, show less biogeographical restrictions in their distribution than platform interior taxa, and have high rates of evolution. The principal groups include *Tremastegina-Helicostegina*, the lepidocyclinids, the nummulitids, and the miogypsinids. *Helicostegina*, the lepidocyclinids, and the miogypsinids all show a continuous endemic evolutionary development in the Americas, whereas the nummulitids show repeated episodes of migration into the region. The present scheme is largely based on the FAD or LAD of a single or two species. As further studies are completed, additional taxa will be added and this will lead to the recognition of assemblages rather than relying on single species or lineages. However, since the Eocene zonation is being applied to successions elsewhere (*e.g.*, TORRES-SILVA & HOHENEGGER, 2024, for Cuba), we feel that publishing of the complete scheme at this time is useful. Refinements to the scheme can therefore be added as new information becomes available.

Our biostratigraphy has largely been based on sections in Jamaica, where most zones within the scheme are present (either in shallow-water limestones associated with carbonate platforms, or reworked into deep-water limestones flanking platforms (*cf.* MITCHELL *et al.*, 2022). The Gulf Coast of the United States (Florida and Alabama) contain good developments and some of the Paleocene to Early Miocene zones, whereas Antigua, Puerto Rico, and the Petite Antilles contain intervals associated with the early Oligocene, late Oligocene to Early Miocene, and Pliocene, respectively.

The latest Cretaceous and Cenozoic saw major perturbations in marine environments driven by extra-terrestrial impacts (K-Pg boundary), climatic optima and MILANKOVITCH-driven temperature/sea-level fluctuations. Shallow-water LBF living on tropical carbonate platforms were significantly affected by some of these events, and some of the American zonal boundaries correspond to such environmental perturbations. The zonation scheme includes immigration events, evolving lineages, and extinction events (Fig. 1).

The K-Pg extinction wiped out many American Cretaceous LBF and it was only in the mid Paleocene that new LBF appeared. These include the orthophragmines (which are not used in the current zonation) and *Ranikothalia*. The extinction of *Ranikothalia* at the Paleocene-Eocene boundary (Larger Benthic Foraminiferal Event 1: LBFE1) in the Americas is broadly coincident with the Paleocene-Eocene Thermal Maximum (PETM) suggesting environmental control.

In the mid Ypresian, a radiation involving *Helicostegina* began (LBFE2), but many of the species are difficult to distinguish in random sections and, other than for the easily recognizable *Helicostegina wellsi*, they are not used in the zonation. *Helicostegina* (excluding the unrelated *Helicolepidina*) disappears at the top of American Benthic Zone (ABZ) 9 (LBFE5).

▶ **Figure 1:** ABZ for the Cenozoic of the Americas with ranges of selected larger benthic foraminifers calibrated against calcareous nannoplakton and planktic for aminifers, foraminiferal events (LBFE), oxygen and carbon isotope stratigraphies (SPEIJER *et al.*, 2020), and global paleoenvironmental events. Standard Benthic Zones (SBZ) for the Tethys are shown for comparison. EOT-1, Eocene-Oligocene terminal event; PrOM, Priabonian thermal maximum; PETM, Paleocene-Eocene thermal maximum.
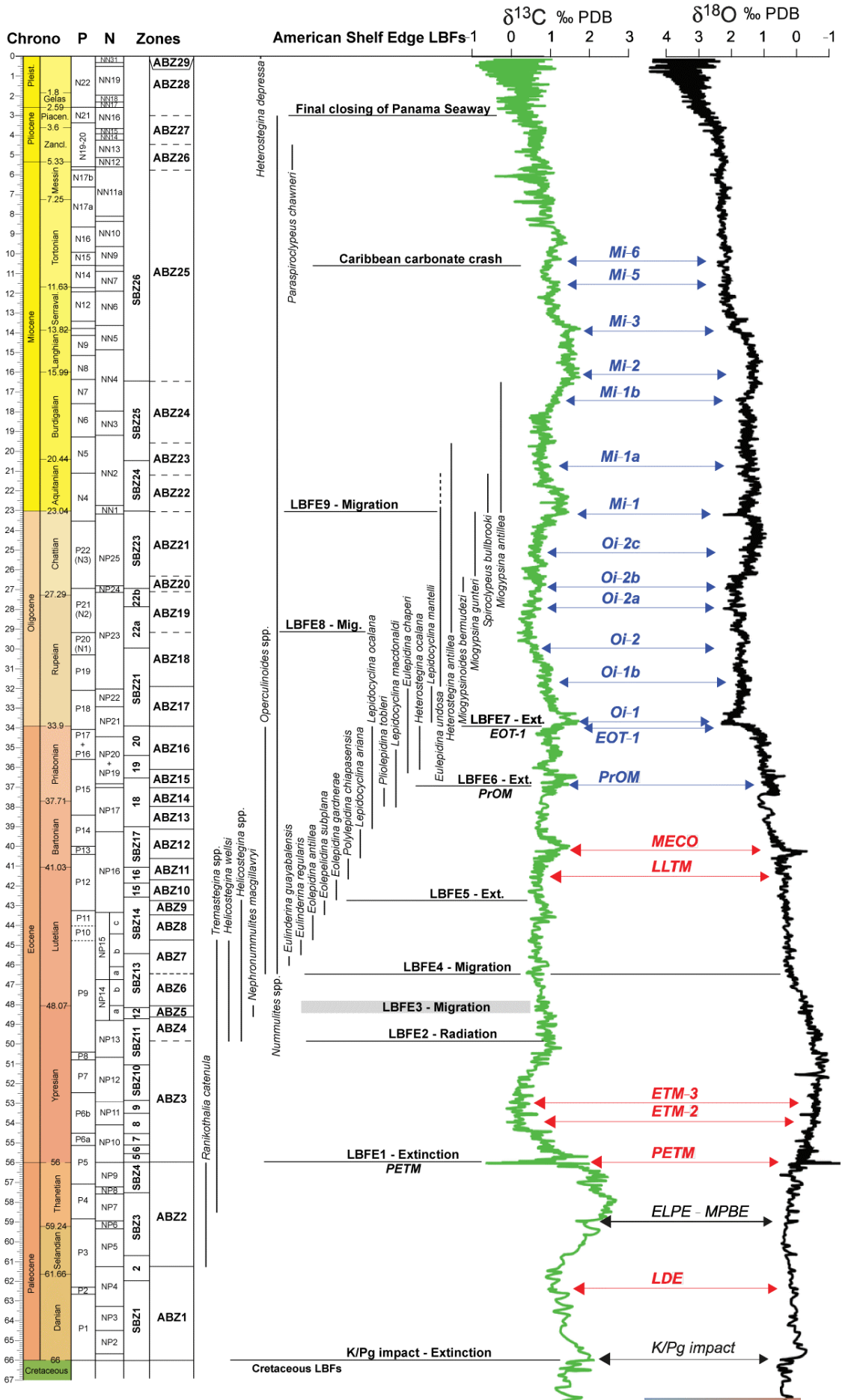
Nummulitids (*Nephronummulites macgillavryi*) reappear in the latest Ypresian, but disappear at the boundary with the Lutetian. This short influx of *Nephronummulites macgillavryi* (LBFE4) with the microspheric form about eight times the size of the megalospheric form, suggests an affinity with Tethys forms (late Ypresian to Bartonian: *e.g.*, BouDAGHER-FADEL & PRICE, 2014), which also show similar size differences. However, the embryo of megalospheric *Nephronummulites macgillavryi* has a large, broadly circular protoconch and a narrow crescent-shaped deteroconch (MITCHELL *et al.*, 2022), which contrasts with the sub-equal first two chambers in the embryos of the Tethys forms (BouDAGHER-FADEL & PRICE, 2014), and they may not be closely related.

A major migration event marks the base of ABZ6 in the mid Lutetian (LBFE3), which sees appearances of many taxa including small nummulitids (variously attributed to *Nummulites* and *Operculinoides*), *Pseudolepidina*, *Linderina*, and the first lepidocyclinids (*Eulinderina* and *Planorbitoinella*; MITCHELL *et al.*, 2022). The lepidocyclinids show a major radiation throughout the rest of the Eocene that is used to establish a high-resolution zonation. The evolution from *Eulinderina* through *Eolepidina* and *Polylepidina* to *Lepidocyclina* (Fig. 2.7-11) shows a reduction in the length of the primary spire from 7-9 chambers in *Eulinderina* to an embryo of two chambers in *Lepidocyclina*, and the development of lateral chambers from *Eolepidina* onwards (ADAMS, 1987; MITCHELL *et al.*, 2022). Populations of specimens show consistent numbers of chambers in the primary spire and calculated means are used for the zonation. The subsequent evolution of the lepidocyclinids shows the development of adauxilary chambers from the deuteroconch and eventually the protoconch, and an increase in the size of the deuteroconch which progressively enwraps the protoconch (Fig. 2.15-16).

Two LBF extinction events characterize the later Eocene. The top of ABZ14 (LBFE6) sees the extinction of *Pliolepidina* (Fig. 2.13) and the platform-interior *Yaberinella*, and corresponds with the Priabonian oxygen maximum (PrOM). The top of ABZ16 (LBFE7) sees the loss of many typical Eocene taxa, including *Heterostegina ocalana*, *Fabularia verseyi*, *Coskinolina* cf. *douvillei*, *Pellatispirella matleyi*, *Pseudochrysalidina*, *Pseudophragmina*, *Asterocyclina*, *Helicolepidina*, and *Butterliniana cubensis* (ROBINSON, 2004) The top of ABZ16 is associated with an oxygen stable isotope excursion marking the onset of glaciation in the Antarctic and changes in ocean circulation patterns (Eocene-Oligocene Transition 1/EOT 1 and Oxygen isotope event 1/Oi 1 (SPEIJER *et al.*, 2020). We ascribe the occurrence of typical Eocene taxa in turbidites in the early Oligocene of Cuba (MOLINA *et al.*, 2015) as probably due to reworking.

During the Oligocene important new taxa appear including *Eulepidina undosa* (Fig. 3.2-3) and its allies, *Heterostegina antillea* (Fig. 3.6-7), and the evolutionary development of the miogypsinids (Fig. 3.4-5, 8-9). The miogypsinids show a progressive evolution from a simple spired (*Neorotalia*) ancestor with the progressive development of a fan of equatorial chamberlets, lateral chamberlets, and the reduction in the length of the primary spire. Some work utilizing random sections (BouDAGHER-FADEL & PRICE, 2010) has suggested a complex evolution, but the interpretation of random sections is not straight forward. We presently use COLE's (1957) simplified classification of the miogypsinids, but future work on assemblages of free specimens, tied to the chronostratigraphy, rather than in random thin sections of rock is needed for subsequent refinement of the zonation.

In the Miocene there is a progressive loss of LBF diversity, with sequential extinctions of *Heterostegina antillea*, *Miogypsina*, *Eulepidina*, and *Lepidocyclina*. This presumably relates to long-term climatic change linked to the development of nutrient upwelling in the Caribbean region (EDINGER & RISK, 1994) and finally a loss of carbonate productivity (the Caribbean carbonate crash) (ROTH *et al.*, 2000). Subsequently, in the Late Miocene, the platform margins of the Americas had relatively low-diversity LBF assemblages dominated by *Amphistegina* and soritids, although *Nummulites* and *Paraspiroclypeus chawneri* (ABZ26 and ABZ27) occur in the early Pliocene (ANDREIEFF, 1983). The final extinction of *Nummulites* might be due to the closure of the Panama Seaway at around 2.7 Ma (Fig. 1; *e.g.*, LUNT *et al.*, 2008; ÖĞRETMEN *et al.*, 2020). *Heterostegina depressus* appears in the late Holocene as an immigrant from Tethys and can be taken as a biostratigraphic proxy close to the base of the Anthropocene (ABZ29).

The new zonation (Fig. 1) will allow a correlation of successions across the tropical Americas with the international chronostratigraphy and allow a better understanding of the development of carbonate platforms during the Cenozoic.

2. Description of zones

ABZ1. From the LAD of Cretaceous LBFs to the FAD of *Ranikothalia* spp. The end Cretaceous mass extinction wiped out the LBF assemblages of the Americas which were characterized by species including *Orbitoides*, *Omphalocyclus*, and *Chubbina* (*e.g.*, GUNTER *et al.*, 2002; MITCHELL, 2005). ABZ1 represents a low diversity zone before the appearance of new LBF lineages in the Paleogene. ABZ1 is calibrated with zones NP1 to NP4. The zone is well-developed in the Nonsuch Limestone in Jamaica (ROBINSON & WRIGHT, 1993) and Costa Rica (BAUMGARTNER-MORA & BAUMGARTNER, 2017).
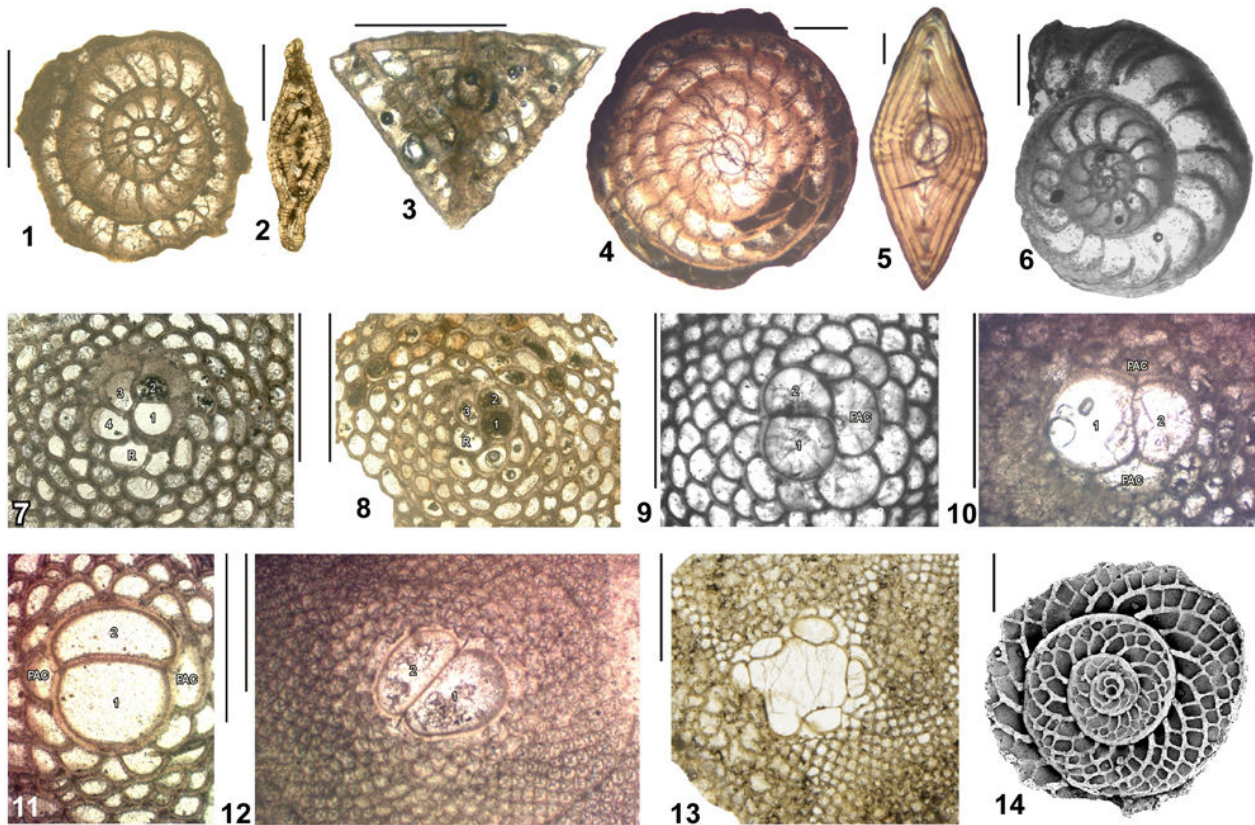
Figure 2: Cenozoic foraminifera from the Americas (Jamaica unless otherwise stated): **1** (E) **- 2** (A), *Ranikothalia catenula* (Cushman & Jarvis), EO.WL2062-33, Nonsuch Formation, Nonsuch; **3** (A), *Helicostegina wellsi* (Cole & Bermúdez), EO.WL2044-75, Chapelton Formation, Lilyfield; **4** (E) **- 5** (A), *Nephronummulites macgillavryi* (Rutten), UWIGM.WL3315-05/03, Palmetto Grove Formation, Hampstead; **6** (E), *Operculinoides* sp., UWIGM.WL3353-07, Preston Hill Formation, Jeffrey Town; **7** (E), *Eolepidina antillea* (Cushman), EO.WL2046-25, Preston Hill Formation, Lilyfield; **8** (E), *Eo. subplana* Barker & Grimsdale, EO.WL2044-36), Chapelton Formation, Lilyfield; **9** (E), *Eo. gardnerae* Cole, UWIGM.Content.3327ft-6, Yellow Limestone, Content Well (depth 3327ft = 1014 m); **10** (E), *Polylepidina chiapasensis* Vaughan, UWIGM.WL2837-08, Preston Hill Formation, Salt Spring; **11** (E) *Lepidocyclina ariana* Cole & Ponton, UWIGM.WL3571-2, Yellow Limestone, Grants Pen; **12** (E) *Lepidocyclina ocalana* Cushman, UWIGM.WL2635-9, Ipswich Formation, Ipswich; **13** (E) *Pliolepidina tobleri* Douvillé, NHM.PM.P.52831, Nicaragua; **14** (E), *Heterostegina ocalana* Cushman, ER176, White Limestone (chalk), Dressikie. E - equatorial section, A - axial section. Scale bars - 500 µm. NHM, Natural History Museum London. OZ, Geological Engineering Department of Istanbul Technical University, Turkey; UWIGM, UWI Geology Museum, Kingston, Jamaica.

ABZ2. From the FAD to the LAD of *Ranikothalia* spp. The zone contains *Ranikothalia* spp. (Fig. 2.1-2) in association with orthophragmines (Özcan *et al.*, 2019, 2022) and can be calibrated with NP5 to NP7 in Jamaica (Jiang & Robinson, 1987). Based on Sr-isotopes *Ranikothalia catenula* ranges through the Seladian and Thanetian, but could potentially range into the early Ypresian based on the associated error bars (Baumgartner-Mora & Baumgartner, 2017). We provisionally place the top of ABZ2 at the top of the Thanetian (top of NP9), pending further work. The zone marks the probable first migration of nummulitids into the American province during the Cenozoic. Subdivision of the zone may be possible based on orthophragmines (Özcan *et al.*, 2019), but further work is needed.

ABZ3. From the LAD of *Ranikothalia catenula* to the FAD of *Helicostegina wellsi*. The zone lacks diverse LBF other than for *Tremastegina*, orthophragmines, and dictyoconids. We calibrate ABZ3 with NP10 to NP12. Localities in the Americas with good representatives of zones ABZ3 to ABZ16 have been given by Mitchell *et al.* (2022).

ABZ4. From the FAD of *Helicostegina wellsi* to the FAD of *Nephronummulites macgillavryi*. The zone sees the appearance of *Helicostegina* (=*Eoconuloides*) in abundance and represents an increase in diversity of LBF. *Helicostegina wellsi* (Fig. 2.3) is distinctive, but relatively long ranging. The zone can be calibrated with lower NP14a (Mitchell *et al.*, 2022). LBF faunas from NP13 are at present unknown.

ABZ5. From the FAD to the LAD of *Nephronummulites macgillavryi* (Fig. 2.4-5). The zone can be calibrated with upper NP14a (Mitchell *et al.*, 2022). The zone marks the second migration of nummulitids into the American province. The top of the zone corresponds with, or is just below, the Ypresian-Lutetian boundary.

ABZ6. From the LAD of *Nephronummulites macgillavryi* to the FAD of *Operculinoides* spp./*Nummulites* spp. The zone is a relatively low-diversity
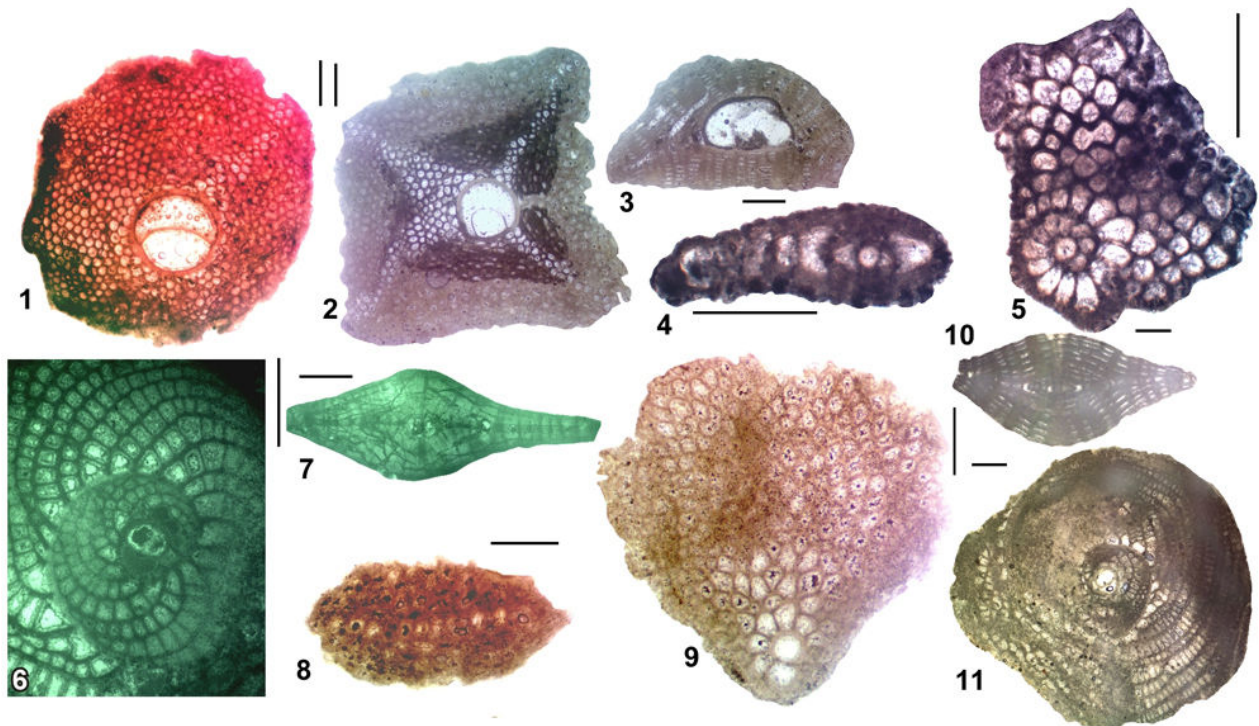
Figure 3: Cenozoic foraminifera from the Americas (Jamaica): **1** (E) *Eulepidina chaperi* (LEMOINE & R. DOUVILLÉ), UWIGM.WL4996-06, Browns Town Formation, Browns Town (ABZ17); **2** (E, UWIGM.WL4475B-3) **- 3** (A, UWIGM. WL4475B-10), *Eulepidina undosa* CUSHMAN, Chalk, Ramble, Westmoreland (ABZ18); **4-5** (UWIGM.R118), *Miogypsinoides bermudezi* DROOGER, chalk, Sherwood Content (ABZ20); **6** (UWIGM.WL4498B-2) - **7** (UWIGM.WL4498B-1), *Heterostegina antillea* CUSHMAN, chalk, Montego Bay (ABZ23); **8** (E, UWIGM.WL5008.20) **- 9** (A, UWIGM.WL5008. 21), *Miogypsina tani* DROOGER, Montpelier Formation, Hope Bay, Portland (ABZ22); **10** (UWIGM.WL5008.2) - **11** (UWIGM.WL5008.5), *Spiroclypeus bullbrooki* (VAUGHAN & COLE), Montpelier Formation, Hope Bay, Portland (ABZ22). Scale bar = 500 µm.

interval during which nummulitids are absent. The zone can be calibrated with NP14b (MITCHELL *et al.*, 2022).

ABZ7. From the FAD of *Operculinoides* spp./*Nummulites* spp. to the FAD of *Eolepidina antillea*. The base of the zone is marked by the appearance of numerous taxa including *Operculinoides* spp. (Fig. 2.6), *Nummulites* ex gr. *striatoreticulatus*, *Pseudolepidina trimera*, *Eulinderina guayabalensis*, *Linderina floridensis*, and others, which represents a major migration event (the third migration of nummulitids into the American province). The zone is calibrated with NP15b (MITCHELL *et al.*, 2022). NP15a is represented by a hiatus in Jamaica. Elsewhere, more primitive taxa of some lineages (without independent calibration) are associated with *Operculinoides* spp. and we tentatively place the base of the zone within NP15a (MITCHELL *et al.*, 2022).

ABZ8. From the FAD of *Eolepidina antillea* to the FAD of *Eolepidina subplana*. The zone calibrates with upper NP15b to NP15c. ABZ7 to ABZ12 show the progressive evolution of primitive members of the lepidocyclinid lineage and show the appearance of lateral chamberlets and the gradual reduction of coiled equatorial chambers to a *Lepidocyclina*-type embryo (MITCHELL *et al.*, 2022).

ABZ9. From the FAD of *Eolepidina subplana* to the FAD of *Eolepidina gardnerae*. The zone is calibrated with lower NP16 (MITCHELL *et al.*, 2022).

ABZ10. From the FAD of *Eolepidina gardnerae* to the FAD of *Polylepidina chiapasensis*. The zone is calibrated with lower mid NP16 (MITCHELL *et al.*, 2022).

ABZ11. From the FAD of *Polylepidina chiapasensis* to the FAD of *Lepidocyclina ariana*. The zone can be calibrated with upper mid NP16 (MITCHELL *et al.*, 2022).

ABZ12. From the FAD of *Lepidocyclina ariana* to the FAD of *Lepidocyclina ocalana*. The zone is calibrated with upper NP16 to possibly lower NP17 (MITCHELL *et al.*, 2022).

ABZ13. From the FAD of *Lepidocyclina ocalana* to the FAD of *Pliolepidina tobleri*. The assemblage is characterised by the appearance of species of *Lepidocyclina* with adauxillary chambers. We calibrate ABZ13 primarily with lower-mid NP17 (MITCHELL *et al.*, 2022).

ABZ14. From the FAD to the LAD of *Pliolepidina tobleri*. The zone is characterized by the distinctive species *Pliolepidina tobleri*. We calibrate ABZ14 with upper NP17 (MITCHELL *et al.*, 2022).

ABZ15. From the LAD of *Pliolepidina tobleri* to the FAD of *Heterostegina ocalana*. We calibrate ABZ15 with NP18 and lower NP19/20 (*sensu* MARTINI, 1971).

ABZ16. From the FAD to the LAD of *Helicostegina ocalana*. The zone corresponds to the migration of *Helicostegina ocalana* into the Americas.

We assign ABZ16 to NP19/20 through lower NP21 (MITCHELL *et al.*, 2022).

ABZ17. From the LAD of *Heterostegina ocalana* to the FAD of *Eulepidina undosa*. It is characterized by a relatively low diversity assemblage of LBFs including *Eulepidina chaperi* (Fig. 3.1), *Lepidocyclina yurnagunensis*, and *Orbitoina* sp. in the Walderston and lower Browns Town limestones of Jamaica and *Lepidocyclina mantelli* and *Nummulites dia* in the Marianna Limestone of the Gulf Coast (VAUGHAN, 1927; COLE & PONTON, 1930). We calibrate ABZ17 with mid NP21 to NP22.

ABZ18. From the FAD of *Eulepidina undosa* to the FAD of *Heterostegina antillea*. The LBF are characterized by *Eulepidina undosa* (Fig. 3.2-3), *Eu. favosa*, *Nephrolepidina* spp., *Lepidocyclina supera*, and *Nummulites* spp. Sr ratios determined from screened calcite in *Kuphus* tubes from ABZ18 indicate ages ranging from 28.5 to 31.5 Ma (late Rupelian). In Alabama *Eulepidina undosa* appears in lower P19/lower O2 (GRAVEL & HANNA, 1937; MILLER *et al.*, 2008) and we place the base of ABZ18 at this level. The zone is widely distributed in the Americas from northern Florida and Jamaica.

ABZ19. From the FAD of *Heterostegina antillea* to the FAD of *Miogypsinoides bermudezi*. This zone contains a LBF assemblage consisting of *Heterostegina antillea* (Fig. 3.6-7), *Eulepidina undosa*, *Eu. favosa*, *Eu. gigas*, *Nephrolepidina* spp., *Nummulites* spp.,, and *Neorotalia mexicana*. We place the base of ABZ19 at the base of zone P21 (ROBINSON, 2004). The zone is well developed in the upper part of the Browns Town Formation in Jamaica (MITCHELL, 2013).

ABZ20. From the FAD of *Miogypsinoides bermudezi* to the FAD of *Miogypsina gunteri*. The base of the zone corresponds to the evolutionary development of *Miogypsinoides* (Fig. 3.4-5) from *Neorotalia*. Earlier work (DROOGER, 1952, 1993) suggested an idealized evolutionary scheme for the miogypsinids of the Americas, however they were poorly stratigraphically constrained and subsequent work has not confirmed this (BAUMGARTNER-MORA *et al.*, 2008). The LBF includes *Heterostegina*, *Eulepidina undosa*, and *Miogypsinoides*. In Antigua *Miogypsinoides* first appears within zone NP25 near the base of P22 and this is confirmed based on Sr-isotope ratios (ROBINSON *et al.*, 2017). The zone is well-represented in the Antigua Formation of Antigua (ROBINSON *et al.*, 2017) and in deep-water chalks in northern Jamaica (unpublished).

ABZ21. From the FAD of *Miogyspina gunteri* to the FAD of *Spiroclypeus bullbrooki*. The zone is characterized by *Miogyspina* (Fig. 3.9) with long primary spires of more than one whorl (ROBINSON *et al.*, 2017). The LBF assemblage includes *Eulepidina undosa*, *Miogyspina gunteri*, and *Heterostegina antillea*. In Puerto Rico *Miogyspina gunteri* occurs in the San Sabastian Formation (SACHS, 1959) that is calibrated with the late Oligocene

based on Sr isotopes (ORTEGA-ARIZA *et al.*, 2015). This is consistent with Sr-isotope and biostratigraphic data from Carriacou (BAUMGARTNER-MORA *et al.*, 2008), and we place the base of ABZ21 low in zones P23 and NP25. The zone is represented in Puerto Rico and Caaiacou (SACHS, 1959; BAUMGARTNER-MORA *et al.*, 2008), but has not yet been recorded in Jamaica.

ABZ22. From the FAD to the LAD of *Spiroclypeus bullbrooki*. The zone is characterized by *Miogypsina* with a spire of less than one whorl in association with *Nummulites*, *Lepidocyclina canellei*, and small specimens of *Miogyspina tani*. *Spiroclypeus bullbrooki* (Fig. 3.10-11) appears suddenly at the base of the zone as an immigrant. This LBF assemblage has previously been assigned to the late Oligocene due to the higher placement of the Oligocene-Miocene boundary in the Americas compared with Europe (VAUGHAN & COLE, 1943; AKERS & DROOGER, 1957; COLE, 1957). However *Spiroclypeus bullbrookei and Miogyspina tani* occur in zone N4 (=M1) in eastern Jamaica (ROBINSON, 2004) and we place the base of ABZ22 at the base of N4. The zone is well-developed in eastern Jamaica (ROBINSON, 2004).

ABZ23. From the LAD of *Spiroclypeus bullbrooki* to the LAD of *Heterostegina antillea*. The last representatives of *Eulepidina* and *Lepidocyclina* also occur in this zone. The top of ABZ23 is placed within N5 (ROBINSON, 2004). Zones ABZ23 to ABZ28 are developed only locally, and further work is needed to understand their foraminiferal assemblages.

ABZ24. From the LAD of *Heterostegina antillea* to the LAD of *Miogypsina*. This marks the final extinction of *Miogypsina* in the Americas. The top of ABZ24 is placed at the top of N7 (ROBINSON, 2004).

ABZ25. From the LAD of *Miogypsina* to the FAD of *Paraspiroclypeus chawneri*. The zone is characterized by the presence of *Nummulites*, but cannot at present be distinguished from ABZ27 unless ABZ26 is present.

ABZ26. From the FAD to the LAD of *Paraspiroclypeus chawneri*. In the Petites Antilles the range of *Paraspiroclypeus chawneri* is calibrated with zones N18 and N19 (ANDREIEFF, 1983).

ABZ27. From the LAD of *Paraspiroclypeus chawneri* to the LAD of *Nummulites*. In the Petites Antilles *Nummulites* ranges up into the middle part of N21 (ANDREIEFF, 1983). This might be related to the final closure of the Panama Seaway (Fig. 1; *e.g.*, LUNT *et al.*, 2008; ÖĞRETMEN *et al.*, 2020).

ABZ28. From the LAD of *Nummulites* to the FAD of *Heterostegina depressa.* The zone is characterized by the presence of *Amphistegina* in the absence of *Nummulites*.

ABZ29. From the FAD of *Heterostegina depressa* to the present*.* The zone is characterized by the presence of *Heterostegina depressa* (prob-

ably a Tethys immigrant brought in via ships) in association with *Amphistegina* and is a proxy for the Anthropocene. This foraminiferan is found in modern beach sands in the Caribbean.

3. Future work

We are currently studying selected sections in the Americas to provide additional information on foraminiferal assemblages associated with each zone. We will publish these updates separately which will lead to a more robust understanding of the foraminiferal succession through the Paleogene and Neogene.

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Author contributions

S.F.M. designed the project, collected and cut material, prepared photographs and taxonomic reviews, prepared the initial draft, edited the initial draft. E.R. provided photographs and taxonomic reviews, edited the initial draft. E.Ö. collected and cut material, provided photographs and taxonomic reviews, edited the initial draft. M.M.J. undertook nannofossil identification on split samples, edited the initial draft. N.R. prepared thin sections, edited the initial draft.

Data and materials availability

All data are available in the main text (specimens are deposited in the UWI Geological Museum, Jamaica, and the Geological Engineering Department of Istanbul Technical University, Turkey)

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