Advances in the biostratigraphy of Paleogene larger benthic foraminifera

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INTRODUCTION

Larger benthic foraminifera (LBF) are important components of shallow-marine carbonate sediments found in the tropic and subtropics. They developed and diversified multiple times during the Phanerozoic: first during the late Paleozoic with the fusulinids that went extinct at the Permian/Triassic boundary, a second time during the Cretaceous with the orbitolinids, and a third time after the Cretaceous/Paleogene boundary with the evolution of nummulitids, alveolinids, orthophragmines, lepidocyclinids and miogypsinids.

The stratigraphic importance of these groups has been recognized for decades (Hottinger 1960). Nummulitic limestones serve as important hydrocarbon reservoirs in places such as North Africa and these have long attracted the attention of the petroleum industry. One early Nummulite enthusiast (Kirkpatrick 1916) saw them nearly everywhere he looked for them – even in meteorites, which he regarded to be "heterogeneous masses of mineralized nummulites hurled up from a region of intense heat and pressure and plunged suddenly into an intensely cold vacuum" (Kirkpatrick 1916, *"The Nummulosphere"*, p. 195, *corrections & additions*).

In the 1990's a working group was established (IGCP Project 286) that produced a "standard" biozonation for Paleogene to Neogene LBF, which has seen wide application throughout the Neo-Tethys and Middle East. The current Shallow Benthic zonation was originally compiled by Serra-Kiel et al. (1998) for the Danian to Priabonian and by Cahuzac and Poignant (1997) for the Rupelian to Tortonian. The "SBZ" zones are Oppelian in nature, with fuzzy boundaries, and were originally correlated to the timescale of Berggren et al. (1995) using magnetostratigraphy and standard planktonic microfossil zonations (Pignatti and Papazzoni 2017). In the terminology of the latest version of the Stratigraphic Code, the original SBZ consists of "assemblage zones" (North American Commission on Stratigraphic Nomenclature 2021). However, as Serra-Kiel pointed out, these correlations were open to refinement based on future advances in biostratigraphy and chronostratigraphy. Indeed, subsequent studies summarized by Papazzoni et al. (2017a,b) have achieved more accurate correlation of the SBZ to the geological timescale.

The current volume represents a major advance in the utility of the SBZ by providing new calibrations to the geological timescale (Speijer et al. 2020). The paper by Pappazoni et al. (this volume) uses an innovative biostratigraphic approach integrating larger foraminiferal and calcareous nannoplankton zones based on biohorizons instead of the traditional marker species assemblages as used by Serra-Kiel et al. (1998). To underline this new approach, the authors rename the biozones defined by means of biohorizons as SBP (Shallow Benthic Paleocene) zones instead of SB or SBZ. This approach is borrowed from the calcareous plankton stratigraphy, and the new definitions of the SB Zones are presented according to the commonly used calcareous plankton/nannoplankton schemes. Calibration is achieved using magnetostratigraphy and Shaw diagrams, thereby providing absolute age plots for LBF biomarkers. The authors point out the need for a further revision of the Eocene, Oligocene, and Miocene biozones by means of biohorizons, thus opening the research doors to an exciting future in shallow water biostratigraphy.

The study by Ferràndez-Cañadell et al. (this volume) revises and updates the biostratigraphy of larger foraminiferal assemblages in three sections of the Priabonian Sanetsch Formation in the Helvetic Nappes of the Western Swiss Alps. The authors describe a new orthophragminid genus, and a new species of *Rotorbinella*, add them to the larger foraminiferal association characterizing the Priabonian (SBZ 19–20). Interestingly, the evolution of the new genus in the Caribbean and western Tethys illustrates the diachronous parallel evolution of the same qualitative characters in populations that are geographically separated.

The Priabonian LBF from the carbonate platform of the Thrace Basin of Greece are carefully documented in the study by Dimou et al. (this volume). The assemblage consists of 24 taxa, mainly orthophragmines and nummulitids, and is correlated with SBZ 20 of Priabonian age. The study revises the known stratigraphic range of *Asterocyclina stellata stellaris*, which was previously known from older strata.

Meanwhile in the Central Tethys (Iran), LBF including orthophragmines, nummulitids and alveolinids are documented by Forouzande et al. (this volume) from the Jahrum and Pabdeh formations in the Zagros region. Some LBF taxa are listed from the area for the first time. These authors use intercalated globigerinid-bearing horizons to calibrate middle Lutetian to early Bartonian zones SBZ 15–17 to planktonic foraminiferal zone E11. Interestingly, some of the *Alveolina* species are found in younger strata in Iran than in the western Tethys, suggesting a dispersal path from the western Tethys (peri-Mediterranean and Europe) to the central Tethys (Middle East) during the Eocene.

The LBF fauna of the Early Oligocene (Rupelian) Asmari Formation of the Zagros zone of Iran is documented in two papers published in this volume: The paper by Hadi et al. (this volume) examined reticulate *Nummulites* populations from the lower part of the Asmari Formation. The study directly correlates the Early Oligocene (Rupelian) SBZ 21 and 22A to the NP22–23 calcareous nannofossil zones. The authors revise the known stratigraphic distribution of *Nummulites bormidiensis*is and related transitional forms, extending them to the Rupelian (SBZ21 and SBZ22A), i.e., an older age than previously recorded in the Neo-Tethys. The study by Yazdi-Moghadam et al. (this volume) describes the LBF assemblages from the subsurface Asmari Formation in two wells from onshore and offshore Iran drilled by the National Iranian Oil Company Exploration Directorate. Eight species of larger benthic foraminifera are described, including *Nummulites fichteli*, *N. vascus*, *Operculina complanata*, *Archaias operculiniformis*, *Praerhapydionina delicata*, *Austrotrillina striata*, *Peneroplis thomasi*, and *P. evolutus*. The presence of *N. fichteli* and *N. vascus* in the absence of lepidocyclinids was used to correlate the assemblage to the SBZ 21 Zone

Finally, the paper by Cotton (this volume) on Nordic *Nummulites* provides new evidence for something always debated: how far north could / can LBF thrive? The new finding of a nummulite in Denmark reveals just what the possibilities may be in a brave new Anthropocene world dominated by global warming. With the spring 2023 global sea surface temperatures the highest they have ever been [https://www.ospo.noaa.gov/], we can expect to see range expansion by subtropical marine species. Like the geographical expansion of *Amphistegina* in the Mediterranean and along the coast of Africa (e.g., Langer et al. 2013), it may be just a matter of time before we hear about *Peneroplis* in Penzance, *Amphistegina* in Amsterdam, or indeed *Heterostegina* in Helgoland. Nummulosphere, here we come!

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