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TOWARDS A CALIBRATED LARGER FORAMINIFERA BIOSTRATIGRAPHIC ZONATION: CELEBRATING 18 YEARS OF THE APPLICATION OF SHALLOW BENTHIC ZONES

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ABSTRACT: **The Shallow Benthic Zonation is one of the most important achievements of biostratigraphy in the last twenty years. Here we summarize the state of the art in the field of Larger Benthic Foraminifera (LBF) and sketch the main lines of research that are improving the precision and usefulness of this scale. The goal of updating the zonation requires a wealth of data coming not only from biostratigraphic investigations but also from paleoenvironmental analyses, biological knowledge, rigorous taxonomic determination, and understanding of paleobiogeography. The papers collected for this special issue are contributions to this broad research program.**

Guest editors Vlasta Ćosović and Cesare A. Papazzoni dedicate this introductory note to the memory of Lukas Hottinger (1933–2011).

INTRODUCTION

Larger benthic foraminifera (LBF), a taxonomically heterogeneous group of unicellular organisms, are characterized by their complex internal structures, endosymbiosis, and large size. They have inhabited warm, shallow and oligotrophic tropical and subtropical seas (Langer and Hottinger 2000) since the late Paleozoic. Over this period, they achieved great abundance and geographical distribution several times: fusulinids on Permian–Carboniferous shelves; orbitolinids, alveolinids and orbitoids in Cretaceous platform systems; and a variety of groups (alveolinids, nummulitids, complex miliolids, complex rotaliids, orthophragmines, miogypsinids and lepidocyclinids) in Cenozoic shallow seas. The last are the focus of this note.

PALEOECOLOGY AND BIOSTRATIGRAPHY OF LBF

LBF have been used since the nineteenth century both for paleoenvironmental reconstructions and for biostratigraphy. Their paleoenvironmental significance has been much improved over the last three decades because understanding of their functional morphology and ecological requirements has significantly increased, mainly through the study of living representatives (e.g., Hottinger 1983, 1997, 2006; Hallock 1985; Lee and Hallock 1987; Hohenegger et al. 1999; Yordanova and Hohenegger 2007). Nevertheless, further investigations to elucidate the relationship among physical, chemical and biological factors influencing the distribution and population dynamics of the different groups of LBF are still needed.

Regarding biostratigraphy, LBF biozones have been of great importance for dating shallow-water carbonate deposits ever since they were first introduced. Even in recent years, with the increasing importance of alternative stratigraphic methods, these biozones have maintained their central role because in shallow water settings geochemical signals are usually affected by diagenetic bias, magnetostratigraphy often cannot be applied, and planktonic index fossils are either scarce or absent.

Since the 1960s many studies have been carried out on the thick Mesozoic and Cenozoic shallow-marine sequences in the Tethyan realm (Hottinger 1960; Drobne 1977; Schaub 1981; Less 1987; Caus et al. 1996). As Pignatti (1998) underlined, shallow marine sedimentation is strongly influenced by eustatic cycles, therefore intrinsically discontinuous. The superposition of discrete intervals of rock with distinctive LBF assemblages has been observed and tested in several localities, allowing construction of a Cenozoic biozonal scheme which has undergone no substantial changes over more than 50 years.

The calibration between LBF zones and plankton/nannoplankton zones is of prime importance in order to evaluate the timing of ecosystem perturbations and revolutions. Generally speaking, benthic foraminifera are closely controlled by environmental conditions and characterized by a relatively slow evolutionary rate, strong facies dependence, and provincialism. These limitations also apply to LBF, but the evolutionary rates are in this case much higher than for smaller foraminifera, allowing a time resolution to be achieved that is no worse than plankton and nannoplankton biozones. If we look at the Paleogene, according to Vandenberghe et al. (2012) there are 24 LBF biozones over about 43 Ma, with a mean duration of 1.79 Ma/biozone; for comparison, in the same time interval, there are 30 planktonic foraminiferal zones, with a mean duration of 1.43 Ma/biozone, and 24 (NP) or 19 (CP) nannoplankton zones, with mean durations of 1.79 and 2.26 Ma/biozone, respectively.

The Paleogene witnessed the evolution of the LBF from the small and simple K/Pg survivors up to large and internally complex forms, which became quite abundant from the Ypresian onwards, thereby creating a special character to shallow marine facies of that time which is recognizable throughout the (Neo)Tethys. In fact, Paleogene shallow-marine limestones are regularly constituted of significant amounts of LBF tests over a vast area spanning the Caribbean, the Mediterranean, the Near to Far East, and the eastern side of Africa.

THE SHALLOW BENTHIC ZONATION

The taxonomic and stratigraphic revision of the most diverse groups of Paleogene LBF (in particular nummulitids, alveolinids, orthophragmines)

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in the 1970s–1980s eventually resulted in the Tethyan Shallow Benthic (SB) zonation (Cahuzac and Poignant 1997; Serra-Kiel et al. 1998). This zonation scheme correlates shallow-water and pelagic sequences for the Paleocene–Eocene Tethys and was mainly based on the extensive work on alveolinids, nummulitids and orthophragmines by Hottinger (1960), Drobne (1977), Schaub (1981), and Less (1987). Hottinger and Drobne (1980) added to these groups some taxonomically heterogeneous imperforate foraminifera which flourished in the shallowest facies of the Tethyan realm.

As previously mentioned, it is well known that the characteristic assemblages defining the SB biozones are discontinuous, because sedimentation in shallow-marine environments often coincides with transgressive phases separated from under- and over-laying deposits by relatively long-lasted hiatuses. The SB biozones are in principle Oppel zones (Pignatti 1998), whose recognition is made possible by the contemporary presence of several key taxa, not necessarily all of them. They are also inherently discontinuous, with boundaries subject to the stratigrapher's judgment (Hedberg 1976), therefore conceptually different from the plankton/nannoplankton zones which are instead usually defined by the appearance/disappearance of a few index taxa.

A different approach was adopted by Less (1987), who defined the orthophragmine species/subspecies biometrically and built a continuous biozonation scale, with numbered Orthophragmine Zones (OZ) where zonal boundaries are also defined biometrically. The SB zones were applied to a quite large area, more or less coincident with the modern Mediterranean, often referred to as Tethyan bioprovince. Sometimes the same scheme has been used outside of this area, in the Near East and the Indian Ocean regions, but this extension has never been tested properly.

Since the 1970s the correlation of the LBF zones with the nannoplankton/plankton scales and successively with magnetostratigraphy has produced an integrated scheme that will eventually allow the LBF zones to be placed within the standard chronostratigraphic scale (e.g., Gradstein et al. 2012).

UPDATING THE SB ZONES

During the eighteen years since the appearance of the SB zonation, a wealth of data on the morphology, biostratigraphy, and paleogeography of Paleogene LBF became available, leading to significant updates (Fig. 1): (1) Increasing the precision in determining boundaries and achieving further subdivision of the previous standard zones as results of biometric studies on different nummulitid genera such as *Heterostegina* (Less et al. 2008) and *Spiroclypeu*s (Less and Ozcan 2008) or through a multidisciplinary study of a section (Less et al. 2011; Zakrevskaya et al. 2011; Ozcan et al. 2009, 2014, 2015); (2) Increasing knowledge of the characteristic foraminiferal assemblages in standard biozones, due to new studies on composition, ecology, and age attribution of regional faunas spanning from the Pyrenean Basin, to the Adriatic-Apulian area, Greece, Eastern Africa, Turkey, Oman, Pakistan, and Tibet (Benedetti et al. 2010, 2011; Cotton and Pearson 2011, 2012; Zhang et al. 2013; Accordi et al. 2014; Cotton et al. 2014, 2015; Drobne et al. 2014; Kahsnitz et al. 2016); (3) New attempts at correlating the SB zones with isotope and magnetic stratigraphy and with the standard plankton zones (Rodriguez-Pintó 2012, 2013; Gebhardt et al. 2013; Egger et al. 2013; Molina et al. 2016); (4) New studies of foraminiferal assemblages from the Peritethys (Crimea, Northern Caucasus to Mangyschlak, Northern Peri-Aralian areas) and from the Caribbean region (Zakrevskaya 2011; Molina et al. 2016); and (5) New detailed studies of the systematics and inner structures of particular LBF groups, such as rotaliids, larger miliolids, and ophtalmidids (Hottinger 2009, 2014; Benedetti and Briguglio 2012; Benedetti 2015; Briguglio et al. 2011, 2013, 2016).

These recent developments in systematics, isotopic geochemistry, and structural analysis of the complex tests of LBF of the Paleogene in combination with progress in biostratigraphy of shallow marine sediments, Cenozoic paleogeography, and paleoclimate, suggest that it was an opportune time to present the SB zonation in a way that everyone may easily get updated information about the species of this particular group of microfossils. In order to obtain full appreciation of recent progress, an international informal group of micropaleontologists (Workgroup On Larger Foraminifera, WOLF, acronym thanks to Andrea Benedetti, Antonino Briguglio, and Massimo di Carlo) working on Paleogene LBF proposed to integrate all these data into a series of atlases. Traditionally, atlases are considered the most useful tool for field geologists, regional stratigraphers, and paleontologists. After nine meetings of the WOLF (Ankara 2009, Miskolc 2010, Buzet/Zagreb 2011, Vienna and Lipica 2012, Modena 2013, Gànt 2014, Graz 2015, and Leiden 2016), guidelines for the atlases, including a timeline, have been defined. The updated taxonomy, paleoecology and biostratigraphy of the different Paleogene LBF (including over 1150 recorded species) will be presented. It is planned to overcome discrepancies in quantity and quality of data between the Central Tethys area (for which monographs have existed since the late nineteenth century, and more recently from Turkey and the Northern Peritethys) and the Near East Tethyan, Far East Tethyan and Caribbean bioprovinces. This plan includes a revision of the main museum collections of LBF, and expansion of the WOLF to involve micropaleontologists from these regions.

THE SPECIAL ISSUE

The subjects of the session "Towards a calibrated Larger Foraminifera Biostratigraphic Zonation: newest results from Neotethys and beyond," held at the Strati 2015 Congress in Graz, reflect the broad nature of current studies on LBF. Among the specific topics presented are: (1) biostratigraphy of LBF from different bioprovinces, from the Caribbean, through the western (Pyrenean), central (Italy, Austria), and southern Tethys (Tunisia), moving to the Indo-Pacific realm (Pakistan); (2) correlation with other biozonations and paleoenvironmental reconstructions over a wide time span, from the late Paleocene up to the Chattian; (3) evolution of selected lineages of LBF (*Heterostegina*, reticulate *Nummulites*); (4) description of the first findings of some LBF in Peritethyan areas; (5) Sr stratigraphy of the Oligocene–Miocene LBF; (6) application of X-ray microtomography (microCT) in studying the complexity of the inner architecture of LBF tests; and (7) the most updated biometric methods for investigating the characters useful for taxonomy and biostratigraphy of the LBF.

This special issue collects some of the results presented in Graz and is intended as an overview of the most recent developments in research about the Cenozoic LBF, as a step on the path to producing an Atlas of Paleogene LBF. We would like to dedicate this introduction to the memory of the late Professor Lukas Hottinger (Fig. 2), who expressed the aim to participate to this project; every one of us benefited from his vast knowledge of the LBF

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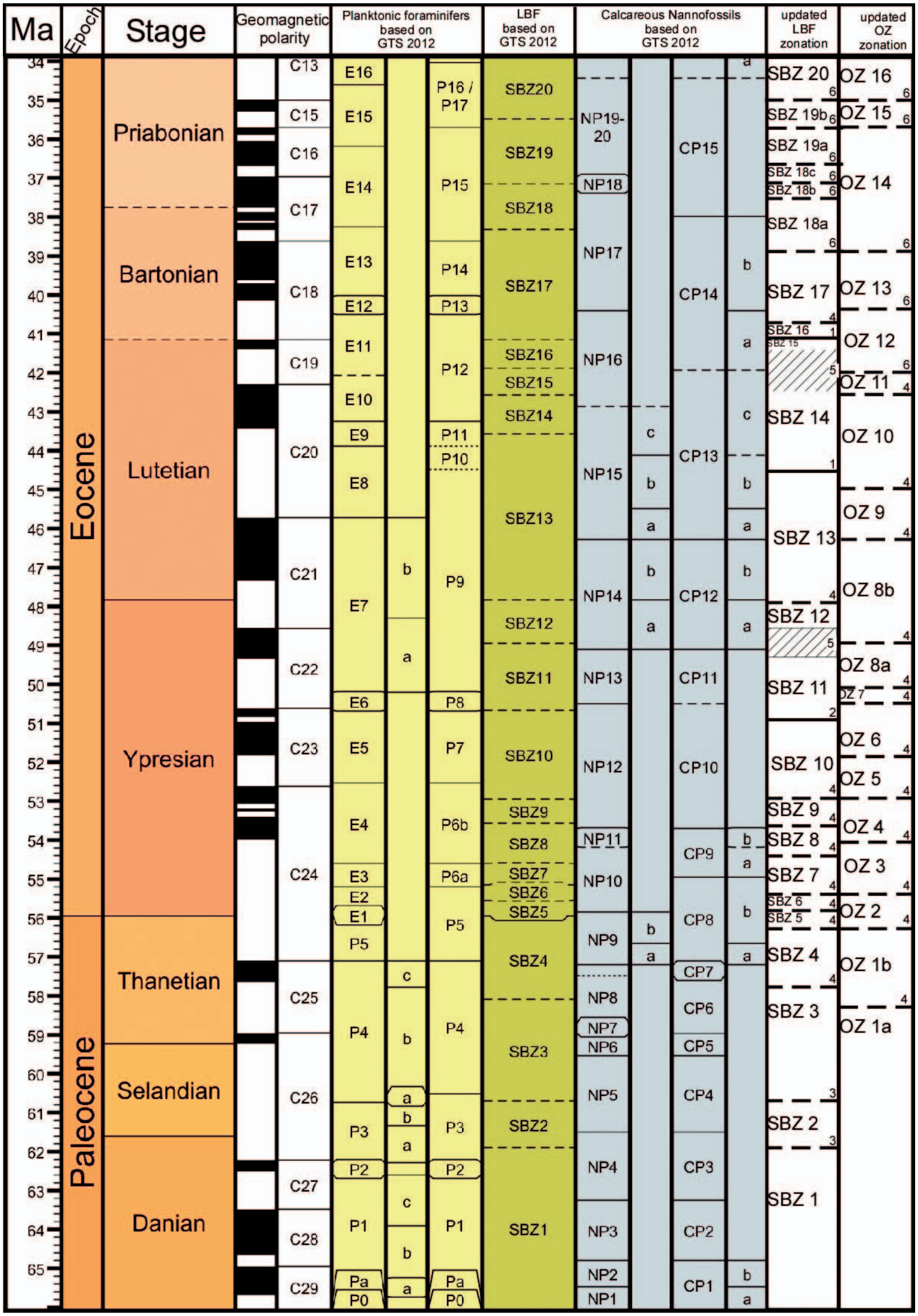
FIG. 1.—Stratigraphic zonation of the Paleocene and Eocene (modified from Vandenberghe et al. 2012). Numbers on boundaries of updated SBZ and OZ zonations (rightmost columns) indicate: 1 = magnetostratigraphic boundaries as proposed by Rodriguez-Pintó et al. (2012); 2 = magnetostratigraphic boundaries as proposed by Rodriguez-Pintó et al. (2013); 3 = boundaries as proposed by Serra-Kiel et al. (1998); 4 = boundaries as proposed by Özcan et al. (2014) by correlations with NP and P zones; 5 = zones of uncertain boundaries as proposed by Rodriguez-Pintó et al. (2012); 6 = Orthophragmine Zone (OZ) boundaries as proposed by Less and Özcan (2012).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LBF based on GTS 2012
Calcareous Nannofossils based on GTS 2012
updated LBF zonation
updated OZ zonation
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Bartonian
Lutetian
Ypresian
Thanetian
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Danian
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FIG. 2.—Lukas Hottinger (1933–2011). Photo courtesy of Katica Drobne.

and researchers will do so well into future through his fundamental contributions to the field.

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