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

4
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18
19 **ABSTRACT**

20 **The Shallow Benthic Zonation is one of the most important achievements of biostratigraphy in the last**
21 **twenty years. Here we summarize the state of the art in the field of Larger Benthic Foraminifera (LBF)**
22 **and sketch the main lines of research that are improving the precision and usefulness of this scale. The**
23 **goal of updating the zonation requires a wealth of data coming not only from biostratigraphic**
24 **investigations but also from paleoenvironmental analyses, biological knowledge, rigorous taxonomic**

25 **determination, and understanding of paleobiogeography. The papers collected for this special issue are**
26 **contributions to this broad research program.**

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28 *This introductory note is dedicated to the memory of Lukas Hottinger (1933–2011).*

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INTRODUCTION

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PALEOECOLOGY AND BIOSTRATIGRAPHY OF LBF

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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, myogypsinids, and lepidocyclinids) in Cenozoic shallow seas. The last are the focus of this note.

LBF have been used since the 19th 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.

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

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

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

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

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THE SHALLOW BENTHIC ZONATION

83 The taxonomic and stratigraphic revision of the most diverse groups of Paleogene
84 LBF (in particular nummulitids, alveolinids, orthophragmines) in the 1970s-1980s eventually
85 resulted in the Tethyan Shallow Benthic (SB) zonation (Cahuzac and Poignant, 1997; Serra-
86 Kiel et al., 1998). This zonation scheme correlates shallow-water and pelagic sequences for
87 the Paleocene-Eocene Tethys and was mainly based on the extensive work on alveolinids,
88 nummulitids and orthophragmines by Hottinger (1960), Drobne (1977), Schaub (1981), and
89 Less (1987). Hottinger and Drobne (1980) added to these groups some taxonomically
90 heterogeneous imperforate foraminifera which flourished in the shallowest facies of the
91 Tethyan realm.

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

126 Zhang et al., 2013; Accordi et al., 2014; Cotton et al., 2014, 2015; Drobne et al., 2014;
127 Kahsnitz et al., 2016).

128 3) New attempts at correlating the SB zones with isotope and magnetic stratigraphy and with
129 the standard plankton zones (Rodriguez-Pintó, 2012, 2013; Gebhardt et al., 2013; Egger et al.,
130 2013; Molina et al., 2016).

131 4) New studies of foraminiferal assemblages from the Peritethys (Crimea, Northern Caucasus
132 to Mangyschlak, Northern Peri-Aralian areas) and from the Caribbean region (Zakrevskaya,
133 2011; Molina et al., 2016).

134 5) New detailed studies of the systematics and inner structures of particular LBF groups, such
135 as rotaliids, larger miliolids, and ophthalmidids (Hottinger, 2009, 2014; Benedetti and
136 Briguglio, 2012; Benedetti, 2015; Briguglio et al., 2011, 2013, 2016).

137 These recent developments in systematics, isotopic geochemistry, and structural
138 analysis of the complex tests of LBF of the Paleogene in combination with progress in
139 biostratigraphy of shallow marine sediments, Cenozoic paleogeography, and paleoclimate,
140 suggest that it was an opportune time to present the SB zonation in a way that everyone may
141 easily get updated information about the species of this particular group of microfossils. In
142 order to obtain full appreciation of recent progress, an international informal group of
143 micropaleontologists (Workgroup On Larger Foraminifera, WOLF, acronym thanks to
144 Andrea Benedetti, Antonino Briguglio, and Massimo di Carlo) working on Paleogene LBF
145 proposed to integrate all these data into a series of atlases. Traditionally, atlases are
146 considered the most useful tool for field geologists, regional stratigraphers, and
147 paleontologists. After nine meetings of the WOLF (Ankara 2009, Miskolc 2010,
148 Buzet/Zagreb 2011, Vienna and Lipica 2012, Modena 2013, Gant 2014, Graz 2015, and
149 Leiden 2016), guidelines for the atlases, including a time-line, have been defined. The
150 updated taxonomy, paleoecology and biostratigraphy of the different Paleogene LBF

151 (including over 1150 recorded species) will be presented. It is planned to overcome
152 discrepancies in quantity and quality of data between the Central Tethys area (for which
153 monographs have existed since the late 19th century, and more recently from Turkey and the
154 Northern Peritethys) and the Near East Tethyan, Far East Tethyan and Caribbean
155 bioprovinces. This plan includes a revision of the main museum collections of LBF, and
156 expansion of the WOLF to involve micropaleontologists from these regions.

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THE SPECIAL ISSUE

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

171 This special issue collects some of the results presented in Graz and is intended as an
172 overview of the most recent developments in research about the Cenozoic LBF, as a step on
173 the path to producing an Atlas of Paleogene LBF. We would like to dedicate this introduction
174 to the memory of the late Prof. Lukas Hottinger, who expressed the aim to participate to this
175 project; every one of us benefited from his vast knowledge of the LBF and researchers will do
176 so well into future through his fundamental contributions to the field.

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327 **FIGURE 1** — Stratigraphic zonation of the Paleocene and Eocene (after Vandenberghe et al.,
328 2012, modified). Numbers on boundaries of updated SBZ and OZ zonations (right-most
329 columns) indicate: 1: magnetostratigraphic boundaries as proposed by Rodriguez-Pintó et al.
330 (2012); 2: magnetostratigraphic boundaries as proposed by Rodriguez-Pintó et al. (2013); 3:
331 boundaries as proposed by Serra-Kiel et al. (1998); 4: boundaries as proposed by Özcan et al.
332 (2014) by correlations with NP and P zones; 5: zones of uncertain boundaries as proposed by
333 Rodriguez-Pintó et al. (2012); 6: Orthophragmine Zone (OZ) boundaries as proposed by Less
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