

1 **The biotic crisis across the Oceanic Anoxic Event 2: palaeoenvironmental inferences based**
2 **in foraminifera and geochemical proxies from the South Iberian Palaeomargin**

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24 15 **ABSTRACT**

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26 16 Open marine sediments of the Cenomanian/Turonian boundary are well exposed in the Spanish
27 17 Baños de la Hedionda section (Betic Cordillera, South Iberian Palaeomargin). The analysis of
28 18 foraminiferal assemblages and geochemical proxies allowed us to infer the impact of the
29 19 oceanic anoxic event 2 (OAE2) in this area of the western Tethys. Three main intervals have
30 20 been identified corresponding to different lithological units and biozones. (1) The top of the
31 21 Capas Blancas Member (*Rotalipora cushmani* Biozone) represents the pre-extinction phase with
32 22 diverse foraminiferal assemblages and a good water-column tiering, with well-oxygenated,
33 23 oligotrophic deep-waters and oxygenated to poorly oxygenated, mesotrophic surface-waters.
34 24 Foraminiferal opportunist species point to a minor event with dysoxic conditions preceding the
35 25 OAE2. (2) The black radiolaritic shales (*Whiteinella archaeocretacea* Biozone) consist of a
36 26 foraminiferal-barren interval, except for the lowermost centimeters where planktic surface-
37 27 dweller opportunists are common. Redox sensitive elements (Cr/Al, V/Al, U/Th, Mo_{EF}, Mo_{aut},
38 28 U_{EF} and U_{aut}) and increased TOC values reflect oxygen depleted conditions related to the OAE2.
39 29 The increase in P/Ti values at the base of this stratigraphic interval indicates an abrupt increase
40 30 in productivity. High concentrations of radiolarians are congruent with high surface productivity
41 31 probably related to changes in oceanic circulation and enhanced upwelling currents, as well as
42 32 subsequent shallowing of the oxygen-minimum zone. The increase in Mo_{EF} and Mo_{aut} towards
43 33 the top of the black radiolaritic shales indicates temporal euxinic conditions. (3) A slow
44 34 recovery of foraminiferal assemblages is recorded at the base of the Boquerón Member
45 35 (*Helvetoglobotruncana helvetica* Biozone), with seafloor recolonization by benthic foraminifera
46 36 being recorded previous to the water column colonization by planktic forms, mainly by

intermediate to deep-dwellers typical of mesotrophic to oligotrophic waters. The subsequent proliferation of surface-dweller opportunists adapted to mesotrophic to eutrophic conditions, and the decrease in planktic foraminiferal diversity, may indicate the persistence of poorly oxygenated conditions in the water column.

Keywords: trophic conditions, redox conditions, foraminifera, OAE2, Cretaceous

1. Introduction

The Oceanic Anoxic Event 2 (OAE2) is represented by the worldwide deposition of organic-rich facies across the Cenomanian/Turonian (C/T) boundary. The OAE2 has been related to palaeoceanographic and climatic changes including greenhouse warming (e.g. Huber et al., 1999, 2002; Norris et al., 2002; Bornemann et al., 2008; Tsandev and Slomp, 2009; Monteiro et al., 2012; Pogge von Strandmann et al., 2013), a perturbation of the carbon cycle (e.g. Kuypers et al., 2002; Erba, 2004; Pogge von Strandmann et al., 2013), a sea-level transgression (Hallam, 1992), and a probable massive magmatic episode (e.g. Kuroda et al., 2007; Turgeon and Creaser, 2008; Erba et al., 2013). The planktic foraminiferal turnover (Coccioni and Luciani, 2004; Caron et al., 2006) includes the disappearance of the genus *Rotalipora* close to the OAE2 (e.g. Hart 1996, 1999; Nederbragt and Fiorentino, 1999; Keller et al., 2001; Coccioni and Luciani, 2004; Reolid et al., 2015). Planktic foraminifera are sensitive to temperature, chemical and trophic conditions of the seawater column and the ecostratigraphic analysis of their assemblages may be used to reconstruct palaeoceanographic changes across the OAE2 (e.g. Jarvis et al., 1988; Huber et al., 1999; Coccioni and Luciani, 2004; Gebhardt et al., 2004, 2010). In addition, the ecostratigraphic analysis of benthic foraminiferal assemblages is a useful tool to interpret fluctuations in oxygen and nutrient availability at the seafloor (e.g. Bernhard, 1986; Koutsoukos et al., 1990; Nagy, 1992; Jorissen et al., 1995; Van der Zwaan et al., 1999; Klein and Mutterlose, 2001; Reolid et al., 2008, 2012a, b). Some authors have interpreted an extinction event affecting benthic foraminiferal assemblages at the C/T boundary (e.g. Peryt and Lamolda, 1996; Kaiho, 1994, 1999; Peryt, 2004), but there is no unanimity (Holbourn and Kuhnt, 2002).

The analysis of redox-sensitive trace elements (such as Cr, Mo, and V, among others) has proved to be a useful tool for interpreting redox conditions during oceanic anoxic events. These elements are less soluble under reducing conditions, resulting in syngenetic enrichments under oxygen-depleted conditions (Wignall and Myers, 1988; Calvert and Pedersen, 1993; Jones and Manning, 1994; Powell et al., 2003; Gallego-Torres et al., 2007; Reolid et al., 2012a, b, 2015). Geochemical proxies have also been successfully applied to

1 73 interpret palaeoproductivity, the most extensively used being Ba/Al and P/Ti ratios (e.g.,
2 74 Turgeon and Brumsack, 2006; Gallego-Torres et al., 2007; Robertson and Filippelli, 2008; Sun
3 75 et al., 2008; Reolid and Martínez-Ruiz, 2012; Reolid et al., 2012a, b). The total organic carbon
4 76 (TOC) has also been employed as an indirect palaeoproductivity proxy (e.g., Gupta and
5 77 Kawahata, 2006; Su et al., 2008), although enhanced TOC contents may result from low
6 78 bottom-water ventilation and oxygen depletion.

7 79 The aim of this work is to integrate planktic and benthic foraminiferal assemblages and
8 80 geochemical proxies to determine the palaeoenvironmental turnover across the OAE2 in the
9 81 Baños de la Hedionda section (Betic Cordillera, South Spain). The OAE2 and the Cenomanian-
10 82 Turonian (C-T) transition are recorded in the Betic Cordillera, where studies on foraminifera,
11 83 calcareous nannoplankton, radiolarian, and trace fossils have been carried out (e.g. Rodríguez-
12 84 Tovar et al., 2009a, b; Sánchez-Quiñónez et al., 2010). Here we present the first integrated
13 85 analysis of benthic and planktic foraminiferal assemblages and geochemical proxies across the
14 86 C–T transition from the Baños de la Hedionda section.

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16 88 **2. Geological setting**

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18 90 The studied section (36°23'39''N, 5°15'45''W) is located in the Málaga province
19 91 (South Spain), 1 km north from Manilva village (Fig. 1). From the geological point of view the
20 92 studied section belongs to the Penibetic, i.e. to the External Zones of the Betic Cordillera (Fig.
21 93 1). The Betic Cordillera is the westernmost Alpine Mediterranean Chain together with the
22 94 Rifian Cordillera in north Morocco. The Betic Cordillera is divided in internal and external
23 95 zones, the last one formed by thin-skinned thrust sheets detached from their basement and
24 96 consisting of thick successions of Triassic to Miocene sedimentary rocks (Vera, 2004). The
25 97 Betic External Zones comprise the Prebetic and Subbetic, which constituted epicontinental and
26 98 epiocceanic environments respectively, from the Early Jurassic. The Baños de la Hedionda
27 99 section is located in the westernmost part of the Internal Subbetic, also called the Penibetic,
28 100 which constituted a moderately deep pelagic plateau located in the most distal part of the South
29 101 Iberian palaeomargin (Martín-Algarra, 1987).

30 102 The Baños de la Hedionda section is located in the eastern limb of the N-S trending
31 103 Canutos de la Utrera anticline, which constitutes a tectonic window among the Cretaceous-
32 104 Tertiary turbiditic successions of the Campo de Gibraltar Flysch Complex. The succession is
33 105 composed by thick limestones of the Líbar Group, surrounded by marly limestones and marls of
34 106 the Espartina Group. The top of the Líbar Group is capped by a decimeter-thick pelagic
35 107 limestone bed with phosphate deposits (stromatolites and macrooncolites) of the latest
36 108 Valanginian–earliest Hauterivian (González-Donoso et al., 1983; Martín-Algarra and Vera,

109 1994; Martín-Algarra and Sánchez-Navas, 2000). The Espartina Group includes the Capas
110 Blancas and the Capas Rojas formations, represented by scaglia-type facies consisting of white
111 and red pelagic marly limestones and marls rich in chert nodules and layers, and characterised
112 by the abundance of planktic foraminifera. The Capas Blancas Formation (~54 m thick) is
113 subdivided in the Capas Blancas Member (~36 m thick) and Boquerón Member (~16 m thick)
114 separated by a < 1.5 m thick bituminous interval that consists of black shales and black
115 radiolaritic interlayers (Martín-Algarra, 1987).

116 The studied interval (Fig. 1c) is 6 m thick and belongs to the upper part of the Capas
117 Blancas Formation. The lowermost 3.2 m consist of marls and marly-limestones with local chert
118 nodules of the Capas Blancas Member (Figs. 1c and 2). These sediments are overlain by 1.45 m
119 of black radiolaritic shales composed by thin laminated black clays and black radiolaritic cherts
120 (Figs. 1c and 2). The uppermost 1.3 m of the studied section consist of white limestones with
121 chert nodules and marls, and belong to the Boquerón Member (Fig. 1c and 2).

122 123 **3. Material and methods**

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125 Lithofacies and microfacies were analysed by field observations and from a total of 19
126 thin sections and 2 polished slabs. Foraminiferal and geochemical analyses were conducted
127 across the C-T transition. A total of 28 sampling levels were selected from this 6 m thick
128 sedimentary succession (Fig. 1).

129 Micropalaeontological samples were disaggregated in water with diluted H₂O₂, washed
130 through a 63 µm sieve, and dried at 50°C. More endurated limestones were immersed in acetic
131 acid (80%) during 1 h to 4 h, depending on the carbonate content, then washed through a 63 µm
132 sieve, and dried at 50°C. Quantitative studies were based on representative splits (using a
133 modified Otto microsplitter) of over 300 specimens of benthic foraminifera larger than 63 µm
134 and 300 specimens of planktic foraminifera larger than 100 µm per sample. The remaining
135 residue was scanned for rare species. Simple diversity (number of species) and the Fisher- α
136 diversity index (e.g. Murray, 1991) were calculated separately for benthic and planktic
137 foraminiferal assemblages.

138 Whole-rock analyses of major elements were carried out in 28 samples using X-ray
139 fluorescence (XRF) in a Philips PW 1040/10 spectrometer. The content of trace elements was
140 determined using an inductively coupled plasma-mass spectrometer (ICP-MS Perkin Elmer
141 Sciex-Elan 5000) at the Centro de Instrumentación Científica (CIC, Universidad de Granada).
142 Instrumental error was $\pm 2\%$ and $\pm 5\%$ for respective elemental concentrations of 50 ppm and 5
143 ppm.

144 The contents in C, N and S, as well as the total organic carbon (TOC) content, were

1 145 analyzed with an Elemental Analyzer LECO CNS-TruSpec and an Inorganic Carbon Analyzer
 2 146 CM5240 UIC in the laboratories of the Centro Andaluz de Medio Ambiente (CEAMA,
 3 147 Granada). Total organic carbon was obtained as the difference between total carbon and total
 4 148 inorganic carbon; it was measured in mg and calculated as percentage of sample weight.

5 149 In order to compare trace-element proportions in samples with varying carbonate and
 6 150 clay contents, trace-element concentrations were normalized to aluminium content (Calvert and
 7 151 Pedersen, 1993). This technique avoids any lithological effects on trace or major element
 8 152 concentrations, assuming that Al content in sediments is heightened by alumino-silicates (e.g.,
 9 153 Calvert, 1990). The study of palaeoproductivity was carried out applying two
 10 154 palaeoproductivity proxies, Ba/Al and P/Ti. To analyze palaeo-oxygenation, two redox proxies
 11 155 evaluating the relative increase of redox sensitive elements, Cr/Al and V/Al, were applied
 12 156 throughout the section as well as the enrichment factors of Mo and U, According to Zhou et al.
 13 157 (2012) and Tribouvillard et al. (2012), the enrichment factors are calculated as $Mo_{EF} =$
 14 158 $[Mo/Al]_{sample}/[Mo/Al]_{PAAS}$ and $U_{EF} = [U/Al]_{sample}/[U/Al]_{PAAS}$. The authigenic values of U and Mo
 15 159 were also calculated according to Zhou et al. (2012), as $Mo_{aut} = [Mo]_{sample} -$
 16 160 $[Mo]_{PAAS}/[Al]_{PAAS} * [Al]_{simple}$, $U_{aut} = [U]_{sample} - [U]_{PAAS}/[Al]_{PAAS} * [Al]_{simple}$.

161 162 4. Results

163 164 4.1. Microfacies

165 166 The top of the Capas Blancas Member corresponds to light (locally dark grey) marls and
 167 167 light grey marly limestones in decimetric beds with black chert nodules and interlayers (Fig.
 168 168 2a). The microfacies range from mudstones to laminated packstones of planktic foraminifera
 169 169 and radiolarids (Fig. 2b).

170 170 The black radiolaritic shales interval is characterised by very dark coloured clay rich
 171 171 layers and radiolaritic layers (Fig. 2c). Thin lamination is persistent in both clay rich layers and
 172 172 radiolarites. The lower part (from 0 – 45 cm) is composed of black clayey radiolarites and dark
 173 173 grey or black silicified shales (both in beds < 5 cm thick). The middle interval (from 45 – 100
 174 174 cm) contains 10 cm of black shales at the bottom, and is characterized by the dominance of
 175 175 black and grey radiolarites with well-laminated black shales interlayers. The upper interval (100
 176 176 – 145 cm) contains alternations of black and grey radiolarites with black and dark grey shales
 177 177 (Figs 2c and d). The top of the black radiolaritic shale interval consists of a 4 cm thick horizon
 178 178 of green clays, overlain by the cherty limestone beds of the Boquerón Member.

179 179 The base of the Boquerón Member is more calcareous and rich in chert nodules than the
 180 180 top of the Capas Blancas Member, but radiolarids are very common (Figs. 2e and f).

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182 4.2. Planktic foraminifera and biostratigraphy

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184 For biostratigraphic assignments, we follow the planktic foraminiferal biozones
 185 proposed by Robaszynski and Caron (1995) for the Cretaceous in Europe and the
 186 Mediterranean. According to Ogg et al. (2012), the C/T boundary is located within the
 187 *Whiteinella archaeocretacea* Biozone.

188 The *Rotalipora cushmani*, *Whiteinella archaeocretacea* and *Helvetoglobotruncana*
 189 *helvetica* biozones have been recognized at the Baños de la Hedionda section. The *Rotalipora*
 190 *cushmani* Biozone (upper Cenomanian) corresponds to the studied interval of the Capas Blancas
 191 Member, except for its uppermost centimeters. This biozone is characterized by trochospiral
 192 keeled planktic forms such as *Rotalipora cushmani*, *Rotalipora monsalvensis*, *Thalmanninella*
 193 *greenhornensis*, *Talmanninella brotzeni*, *Parathalmanninella appenninica*, and
 194 *Thalmanninella deecke*. The *Whiteinella archaeocretacea* Biozone includes the topmost
 195 centimeters of the Capas Blancas Member, the black radiolaritic shales and the first centimeters
 196 of the Boquerón Member. The most common species of this biozone are *Praeglobotruncana*
 197 *stephani*, *Praeglobotruncana gibba*, *Hedbergella delrioensis*, *Marginotruncana sigali*, and
 198 *Globigerinelloides bentonensis*. According to O'Dogherty (1994) and O'Dogherty et al. (2001)
 199 a sudden renewal of radiolarian species in this section delineates the boundary between
 200 *Guttacapsa biacuta* Biozone and *Alievium superbium* Biozone that correlated approximately to
 201 the *Whiteinella archaeocretacea* Biozone. The *Helvetoglobotruncana helvetica* Biozone (lower
 202 Turonian) includes the uppermost meter of the Boquerón Member. This biozone is characterized
 203 by the record of *Helvetoglobotruncana helvetica*, *Helvetoglobotruncana praehelvetica* and
 204 *Guembelitra cenomana*. Other characteristic species recorded within this biozone include
 205 *Marginotruncana marginata*, *Sigalitruncana marianosi* and *Whiteinella inornata*.

206 Planktic foraminiferal assemblages (Fig. 3) are abundant and diverse across the studied
 207 section except for the black radiolaritic shales unit, which is barren of foraminifera (Fig. 4). A
 208 total of 14 genera and 34 species have been recorded.

209 The Capas Blancas Member (samples BH-0 to BH-45) shows P/B values ranging from
 210 97 to 99% (Fig. 4). The number of species of planktic foraminifera is high (17 to 22
 211 species/sample) and the Fisher- α index of diversity ranges between 3.76 and 5.37 (Fig. 4).
 212 According to planktic morphogroups (Fig. 5), assemblages are dominated by trochospiral
 213 morphogroups in the Capas Blancas Member (83.4 to 94.2%), while planispiral planktic
 214 morphogroups make up between 4.7 and 13.1% of the assemblages (Fig. 6). Keeled trochospiral
 215 forms dominate over unkeeled forms. Biserial forms are a minor component of the assemblage
 216 (less than 5%). The most common species include *Praeglobotruncana stephani*, *Thalmanninella*

1 217 *brotzeni*, *Praeglobotruncana gibba*, *Rotalipora cushmani*, *Hedbergella delrioensis*,
 2 218 *Hedbergella planispira*, *Hedbergella simplex*, and *Globigerinelloides bentonensis*. The
 3
 4 219 percentages of the species *Dicarinella algeriana*, *Hedbergella delrioensis*, *Thalmaninella*
 5
 6 220 *greenhornensis* and *Whiteinella aprica* decrease towards the upper half of the Capas Blancas
 7
 8 221 Member, while the percentages *Praeglobotruncana* (mainly *P. gibba* and *P. stephani*) and
 9
 10 222 *Rotalipora cushmani* increase (Fig. 7). Two species disappear in the lower half of this member:
 11
 12 223 *Dicarinella algeriana* reappears higher up in the section, and *Whiteinella aumalensis* has not
 13
 14 224 been observed in any other samples across the studied section. All the identified species but four
 15 225 last occur in the uppermost sample of the Capas Blancas Member (Fig. 7).

16 226 The black radiolaritic shales constitute a barren interval except for the lowermost
 17
 18 227 sample (BH-49), which contains 5 planktic foraminiferal species (*Globigerinelloides*
 19
 20 228 *bentonensis* *Hedbergella delrioensis* *Marginotruncana sigali*, *Praeglobotruncana stephani* and
 21
 22 229 *P. gibba*) but no benthic taxa. The low-diversity (Fisher- α = 2.62, Fig. 4) foraminiferal
 23
 24 230 assemblage is dominated by trochospiral morphogroups (86.7%), mainly keeled forms, followed
 25
 26 231 by planispiral morphogroups (13.3%, Fig. 6). Biserial and triserial planktic foraminifera are not
 27
 28 232 recorded. *Globigerinelloides bentonensis* and *Hedbergella delrioensis* become more abundant
 29
 30 233 in this sample with respect to the underlying Capas Blancas Member, and the species
 31 234 *Marginotruncana sigali* first occurs and makes up 26.7% of the assemblage (Fig. 7).

32 235 The lowermost 50 cm of the Boquerón Member are also barren of planktic foraminifera
 33
 34 236 (Figs. 4, 6 and 7). The P/B ratio in the rest of this unit is high, but it drops down to 0% in
 35
 36 237 sample BH-88 (Fig. 4). The number of planktic species ranges from 11 to 22 species/sample,
 37
 38 238 and the Fisher- α index ranges between 2.99 and 5.48 (Fig. 4). Unkeeled trochospiral forms
 39
 40 239 replace keel trochospiral ones in the upper half of this member (Fig. 6). Biserial and triserial
 41
 42 240 morphogroups are a minor component of the assemblages, and planispiral forms are recorded
 43
 44 241 only in the lowermost sample (BH-83). *Whiteinella baltica*, *Praeglobotruncana stephani*,
 45
 46 242 *Praeglobotruncana gibba*, *Hedbergella delrioensis* and *Dicarinella algeriana* are the most
 47
 48 243 common species (Fig. 7). The lower half of the Boquerón Member is characterized by high
 49
 50 244 percentages of *Dicarinella algeriana*, which was scarcely recorded in the Capas Blancas
 51
 52 245 Member. Other species of *Dicarinella* and the genera *Globoheterohelix* and *Guembelitra* first
 53
 54 246 occur at the base of the Boquerón Member. The middle part of the Boquerón Member is
 55
 56 247 characterized by increasing proportions of *Hedbergella delrioensis* and *Whiteinella baltica* (Fig.
 57
 58 248 7).

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60 250 4.3. Benthic foraminifera

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252 A total of 53 genera and 69 species of benthic foraminifera have been recorded in the
 253 Baños de la Hedionda section (Fig. 8). Calcareous taxa dominate the assemblages (up to 93%)
 254 except for sample BH-23 in the Capas Blancas Member, where agglutinated forms make up to
 255 52.4% of the assemblage. There are no benthic foraminifera in the black radiolaritic shales nor
 256 in the lowermost 10 cm of the Boquerón Member (Fig. 9).

257 The number of benthic foraminiferal species ranges from 17 to 38 in the Capas Blancas
 258 Member, and the Fisher- α diversity index ranges from 5.14 to 14.62 (Fig. 4). Among benthic
 259 morphogroups, the biconvex trochospiral (e.g., *Gyroidinoides globosus*, *Charltonina australis*,
 260 *Charltonina* sp., *Gavelinella cenomanica* and *Gavelinella* sp.) and cylindrical elongated
 261 morphogroups (e.g., *Tritaxia gaultina*, *Laevidentalina* spp., *Praebulimina* spp. and *Marsonella*
 262 *oxycona*) dominate (Fig. 9). Pseudospheric forms such as *Ammosphaeroidina* spp. are also
 263 common in the Capas Blancas Member. The epifaunal forms are more abundant than infaunal
 264 ones (Fig. 10). A significant increase in the percentages of *Charltonina australis* (17.4%, BH-
 265 17), *Gavelinella* spp. (22.8%, BH-17) and *Glomospira* spp. (23.8%, BH-23) has been observed
 266 between meters 1 to 1.5 m in the Capas Blancas Member (Fig. 9).

267 Assemblages recorded immediately above the barren interval in the Boquerón Member
 268 are significantly different from those in the Capas Blancas Member. The number of species
 269 increases from the base (9, sample BH-81) to the top (21, sample BH-88) of the Boquerón
 270 Member, and the Fisher- α index increases from 2.95 to 4.95 (Fig. 4). These values are lower
 271 than in the Capas Blancas Member. Assemblages in the Boquerón Member are dominated by
 272 biconvex trochospiral (*Gyroidinoides beisseli* and *Gyroidinoides globosus*), cylindrical
 273 (*Praebulimina* spp., *Tritaxia gaultina* and *Pleurostomella* spp.) and planoconvex trochospiral
 274 morphogroups (*Stensioeina exsculpta*). Now, infaunal forms are dominant respect to epifaunal
 275 ones (Fig. 10). The lower part of this member is characterized by high proportions of species
 276 that were scarcer in the Capas Blancas Member, such as *Gyroidinoides beisseli* (24.6%),
 277 *Praebulimina* spp. (35.0%), *Stensioeina exsculpta* (17.5%), and *Pleurostomella* spp. (5.3%)
 278 (Fig. 9). Taxa such as *Tappanina* sp. (21.0%), *Gaudryina* spp., *Gavelinella* spp. and *Lenticulina*
 279 spp. are recorded immediately above the lowermost sample of the Boquerón Member (Fig. 9).

281 4.4. Geochemistry

283 4.4.1. Redox proxies

284 The analysis of redox proxies allowed us to subdivide the studied section into three
 285 intervals that correspond to the three stratigraphic units (Fig. 11): the Capas Blancas Member
 286 (*Rotalipora cushmani* Biozone), the black radiolaritic shales (*W. archaeocretacea* Biozone), and
 287 the Boquerón Member (topmost of *W. archaeocretacea* and base of the *H. helvetica* Biozone).

288 The Capas Blancas Member (*R. cushmani* Biozone) is characterized by very low values
 289 of Cr/Al, U/Th, V/Al, Mo_{EF}, Mo_{aut.}, U_{EF} and U_{aut.} ratios, followed by a sudden increase in U/Th,
 290 V/Al, U_{EF} and U_{aut.} ratios in the black radiolaritic shales (*W. archaeocretacea* Biozone), with the
 291 highest values recorded in the upper part of the black radiolaritic shales (Fig. 11). A gradual
 292 increase in Cr/Al, Mo_{EF}, and Mo_{aut.} ratios within the black radiolaritic shales leads to the highest
 293 values in the upper part of this unit. U_{EF} and Mo_{EF} reach significantly high values in the black
 294 radiolaritic shales (7.46 and 22.38, respectively); according to Tribovillard et al. (2012), an
 295 elemental enrichment factor > 3 is considerable, and > 10 is considered as a strong enrichment.

296 At the base of the Boquerón Member limestones (*Helvetoglobotruncana helvetica*
 297 Biozone), the redox ratios decrease down to the original values recorded in the Capas Blancas
 298 Member (Fig. 11).

300 4.4.2. Palaeoproductivity proxies and TOC

301 The selected palaeoproductivity proxies and TOC show the most significant changes in
 302 the black radiolaritic shales (Fig. 12), except for the Ba/Al ratio which shows a prominent peak
 303 in the lower part of the Capas Blancas Member (sample BH-7). A peak in the P/Ti ratio has
 304 been recorded towards the base of the black radiolaritic shales coincident with a strong decrease
 305 in the %CaCO₃ (Fig. 12), which shows very low values in this unit (0.5 – 3.6 wt.%). The TOC
 306 and TS reach the maximum values in the upper part of the black radiolaritic shales (4.8 wt.%
 307 and 2.2 wt.% respectively, sample BH-69), in the same horizon where maximum values in the
 308 redox proxies Cr/Al, V/Al, U_{EF} and U_{aut.} have been recorded (Figs. 11 and 12). TOC and TS
 309 return to lower values and the %CaCO₃ increases at the base of the Boquerón Member
 310 (*Helvetoglobotruncana helvetica* Biozone, Fig. 12).

312 5. Palaeoenvironmental interpretation

314 5.1. Capas Blancas Member: Pre-extinction phase

316 The Capas Blancas Member is characterised by the dominance of planktic foraminifera,
 317 with a good water-column tiering including potential deep-dweller specialists (*Rotalipora* and
 318 *Thalmaninella*), intermediate-dwellers (e.g. *Praeglobotruncana*) and potentially surface-
 319 dweller opportunists (e.g. *Hedbergella* and *Globigerinelloides*). This assemblage composition
 320 indicates well-oxygenated, oligotrophic deep-waters and oxygenated to poorly oxygenated,
 321 mesotrophic surface-waters (Fig. 13). However, some minor changes may be described in the
 322 planktic assemblages. A gradual increase in the percentage of keeled forms (mainly
 323 *Thalmaninella brotzeni*, *Praeglobotruncana stephani* and *Rotalipora cushmani*), parallel to a

1 324 decrease in unkeeled trochospiral forms (mainly *Hedbergella delrioensis* and *Whiteinella*
 2 325 *aprica*) in the lower part of the Capas Blancas Member (Fig. 6) may be related to a lithological
 3 326 change from limestones to marls and marly limestones. This change is correlative with an
 4 327 increase in Ba/Al ratio (Fig. 11), which is a palaeoproductivity proxy (Reolid and Martínez-
 5 328 Ruiz, 2012). However, the P/Ti ratio, another palaeoproductivity proxy, does not show any
 6 329 significant fluctuations.

7 330 Benthic assemblages from the Capas Blancas are slightly dominated by epifaunal forms
 8 331 (e.g. *Gyroidinoides globosus* and *Charltonina australis*) but also contain some components of
 9 332 shallow (mainly *Laevidentalina* spp., *Ammosphaeroidina* spp., and *Marsonella oxycona*) and
 10 333 deep (*Tritaxia gaultina*) infaunal microhabitats (Fig. 10). This assemblage composition points to
 11 334 low mesotrophic conditions in the sea-bottom microhabitats because composition of
 12 335 morphogroups is equilibrated (Fig. 13), except in isolated samples where epifaunal forms are
 13 336 higher than 50%. Typical benthic forms indicative of oxygen poor, eutrophic conditions (such
 14 337 as *Praebulimina*, *Pleurostomella*, *Tappanina*, *Glomospira* and *Gavelinella*; e.g. Koutsoukos et
 15 338 al., 1990; Coccioni et al., 1993; Widmark, 2000; Gebhardt et al., 2010; Reolid et al., 2015) are
 16 339 scarcely represented (Fig. 9). The marly interval of this member, however, contains quantitative
 17 340 peaks in the abundance of *Charltonina australis*, *Gavelinella* spp., *Globorotalites* sp.,
 18 341 *Pleurostomella* spp. *Spiroplectammia roemeri*, *Glomospira* spp. and *Praebulimina* spp.
 19 342 (samples BH-17 to BH-23) which point to decreased sea-bottom water oxygenation (Fig. 13), as
 20 343 *Gavelinella*, *Globorotalites*, *Glomospira*, *Praebulimina* and *Pleurostomella* are indicatives of
 21 344 low oxygen conditions (e.g. Gebhardt et al., 2010; Reolid et al., 2015). *Gavelinella* spp. is a
 22 345 low-oxygen tolerant genus (Sliter, 1975; Koutsoukos et al., 1990; Gertsch et al., 2010), and it
 23 346 occurs in shales with high organic matter levels (Holbourn et al., 2001). *Globorotalites* has been
 24 347 observed to peak under stressful conditions at the seafloor after the Cretaceous/Paleogene
 25 348 impact event (Alegret, 2007; Alegret et al., 2012). The interpretation of dysoxic conditions is
 26 349 supported by a small peak in the U_{EF} (Fig. 11). This minor event within the *Rotalipora*
 27 350 *cushmani* Biozone consists of an ecological replacement of opportunistic taxa, being
 28 351 *Gavelinella* the first colonizer and *Glomospira* and *Praebulimina* the last ones reaching the
 29 352 peaks of their maximum percentages (Fig. 9). Among planktic assemblages, the relative
 30 353 abundance of the deep-dweller specialist *Rotalipora cushmani* and the surface-dweller
 31 354 opportunists *Hedbergella* and *Heterohelix* increase in coincidence with this minor event (Fig.
 32 355 7).

33 356 An increase in the percentage of *Charltonina*, *Glomospira*, *Lenticulina* and
 34 357 *Praebulimina* is recorded immediately above this short interval of dysoxic sea-bottom water
 35 358 conditions (Fig. 9). These genera are not dominant but point to unfavorable conditions in spite
 36 359 of the fact that redox and palaeoproductivity proxies do not change significantly (Figs. 11 and

12). The increase of opportunistic forms prior to an anoxic event and prior to associated variations in geochemical proxies was also documented across the Toarcian Oceanic Anoxic Event by Reolid et al. (2012). A significant decrease in the diversity of benthic foraminifera occurs towards the top of the Capas Blancas Member, and is congruent with the progress of the unfavorable conditions at the seafloor.

Ichnofabric analysis carried out by Rodríguez-Tovar et al. (2009a) revealed the occurrence of *Chondrites*, *Planolites*, *Trichichnus* and *Palaeophycus* at the top of the Capas Blancas Member. These authors interpreted a well-oxygenated environment punctuated by short intervals of oxygen-depleted conditions.

5.2. Black radiolaritic shales: Oceanic Anoxic Event 2

The lack of benthic foraminifera in the black radiolaritic shales, and the occurrence of planktic foraminifera only in the lowermost sample (BH-49), point to adverse conditions during sedimentation of the black shales. Low-diversity planktic assemblages from sample BH-49 (Fig. 4) are dominated by surface-dweller opportunists (*Hedbergella delrioensis* and *Globigerinelloides bentonensis*, Fig. 5), which indicate poorly oxygenated waters and eutrophic conditions (Fig. 13). But in this sample also persists non-opportunist intermediate-dwellers (*Praeglobotruncana gibba* and *Praeglobotruncana stephani*), and abundant *Marginotruncana*. No deep-dweller specialists such as *Rotalipora* and *Thalmaninella* have been found in this assemblage. Apart from sample BH-49, the black radiolaritic shales are barren of foraminifera, suggesting adverse conditions in the water column. Huber et al. (1999) interpreted increased pCO₂ and deep water warming which may have caused a breakdown in the vertical tiering of the water column and could explain the extinction of deeper dwelling planktic species.

Redox conditions in the water column and at the seafloor may be inferred from the analysis of redox-sensitive trace elements (Cr, Mo, U and V), which tend to co-precipitate with sulfides (mainly pyrite) and are usually not remobilized during diagenesis in the absence of post-depositional replacement of oxidizing agents (Tribovillard et al., 2006). The enhancement in redox sensitive elements (Cr/Al, V/Al, U/Th, Mo_{EF}, Mo_{aut}, U_{EF} and U_{aut}) points to depleted oxygen conditions during deposition of the black radiolaritic shales (Figs. 11 and 13). U-based proxies (U_{EF}=7.46 and U_{aut}= 10.07) and increased TOC values (4.84 wt.%) point to depleted oxygen conditions in the lower part of the water column (Fig. 13).

The P/Ti ratio is a commonly used proxy for productivity (Latimer and Filippelli, 2001; Robertson and Filippelli, 2008; Reolid et al., 2012a, b, 2015). Increased values are related to a higher phosphorous supply to the seafloor derived from biological processes, not from terrigenous components (Latimer and Filippelli, 2001; Flores et al., 2005; Sen et al., 2008). At

1 396 Baños de la Hedionda section, the increase in P/Ti values at the base of the *W. archaeocretacea*
2 397 Biozone indicates an abrupt increase in productivity (Fig. 12). Such an increase in the P/Ti ratio
3 398 was also identified at the base of this biozone in the Tunisian Oued Bahloul section in the base
4 399 of the *W. archaeocretacea* (Reolid et al., 2015). Mort et al. (2007) suggested that the increase
5 400 in P-accumulation rates coinciding with the OAE2 may be related to an overall increase in
6 401 surface-water productivity. However, in Baños de la Hedionda section maximum values of P/Ti
7 402 ratio do not coincide with maximum values of TOC or U_{EF} (Figs. 11 and 12). The Ba/Al ratio,
8 403 which has also been used as a palaeoproductivity proxy (Sun et al., 2008; Reolid and Martínez-
9 404 Ruiz, 2012; Reolid et al., 2012a, b), does not show any significant fluctuations in the black
10 405 shales interval.

11 406 Therefore, the initial increase in opportunist planktic foraminifera typical of poorly
12 407 oxygenated environments and eutrophic conditions, and the disappearance of deep-dweller
13 408 specialists (e.g. *Rotalipora*) and benthic forms is congruent with the debut of the OAE2 as well
14 409 as with the high P/Ti values. Persistent oxygen restricted conditions are confirmed by the
15 410 relatively higher TOC values (reaching 4.84 wt.%), which point to higher accumulation of
16 411 organic matter derived from surface primary productivity than in the Capas Blancas Member
17 412 (Schlanger and Jenkyns, 1976; Arthur et al., 1990; Ingall et al., 1993; Van Cappellen and Ingall,
18 413 1994; Mort et al., 2007). TOC values have been used in the literature (e.g., Calvert and
19 414 Fontugne, 2001; Gupta and Kawahata, 2006; Plewa et al., 2006; Su et al., 2008; Reolid et al.,
20 415 2012a) as an indirect palaeoproductivity proxy when TOC is related to phytodetritus associated
21 416 with phytoplankton or dinoflagellate remains. Nevertheless, because high TOC values may
22 417 result from low bottom-water ventilation and oxygen depletion, they are not necessarily related
23 418 to high surface productivity. According to Tribouillard et al. (2006), the TOC is generally
24 419 proportional to surface-water productivity and constitutes a useful palaeoproductivity proxy in
25 420 spite of certain complications attributable to efficient organic recycling, export productivity,
26 421 delivery to the sediment-water interface and final burial.

27 422 Radiolarians are a major component of the black radiolaritic shales (Fig. 2d) and
28 423 indicate abnormally high surface productivity. High concentrations of radiolarians have been
29 424 typically documented from black shales related to the OAE2 in northern European sections
30 425 (e.g., Jarvis et al., 1988; Scopelliti et al., 2004; Kędzierski et al., 2012; Uchman et al., 2013),
31 426 which are often barren of planktic foraminifera. According to Jarvis et al. (1988), major changes
32 427 in oceanic circulation during the C-T transition enhanced upwelling currents, with nutrient-rich
33 428 deep-waters emerging towards the surface. Moreover, abundance of radiolarians in the same
34 429 sediments is congruent with shallowing of the oxygen-minimum zone caused by enhanced
35 430 ocean-surface productivity.

1 431 In the Recent marine environments there is a positive correlation between TOC and
2 432 total sulphur (TS) mainly coming from pyrite (Bernier and Raiswell, 1983). Under depleted
3 433 oxygen conditions (dysoxic or anoxic), the organic matter decays at the seafloor or in the
4 434 sediment-water interface, resulting in increased reduction rates of sulphate, increased H₂S in the
5 435 sediment pore-water, and the progressive shallowing of the redox boundary within the sediment.
6 436 The H₂S reacts with the detritic Fe and forms pyrite. In this sense, the TS in the black shales
7 437 interval is congruent with the highest TOC values and the oxygenation decrease indicated by
8 438 V/Al and Cr/Al ratios (Figs. 11 and 12).

9 439 High Mo_{EF} and Mo_{aut} values require the presence of H₂S (euxinic conditions)
10 440 (Tribovillard et al., 2012; Zhou et al., 2012). The increase in Mo_{EF} and Mo_{aut} across the black
11 441 shales indicates a decrease in oxygen availability towards euxinia (Fig. 13). Other authors have
12 442 reported euxinic conditions from the OAE2 (e.g., Wang et al., 2001; Scopelliti et al., 2004;
13 443 Reolid et al., 2015). The progressive accentuation of oxygen-depleted conditions from the base
14 444 of the black shales upwards is compatible with the disappearance of planktic taxa that flourished
15 445 at the beginning of the eutrophic conditions (e.g., *Hedbergella* and *Globigerinelloides*).

16 446 Marine anoxia during the OAE2 is thought to have been related to enhanced biological
17 447 productivity (e.g. Monteiro et al., 2012; Pogge von Strandmann et al., 2013). Uranium and
18 448 organic matter in the sediment are related, as uranium may form a complex with dissolved
19 449 fulvic acid in hemipelagic sediments (Nagao and Nakashima, 1992). In this sense, high values
20 450 for U_{EF} and U_{aut} are congruent with the high values of TOC. In open-ocean systems with suboxic
21 451 bottom waters, U_{aut} enrichment is greater than that of Mo_{aut} because U_{aut} accumulation begins at
22 452 the Fe (II)-Fe (III) redox boundary (Zhou et al., 2012), while Mo_{aut} accumulation becomes more
23 453 relevant as waters become euxinic. Higher values of U_{aut} recorded in the lower part of the black
24 454 shale interval are congruent with anoxic conditions not only at the sea-bottom waters but also in
25 455 the deeper layers of the water column, where deep dwellers such as *Rotalipora* inhabited.
26 456 However, the upper part of the black shales (BH-69 to BH-79) presents higher values of Mo_{aut}
27 457 than U_{aut} and indicates euxinic conditions.

28 458 Based ichnologic analysis, Rodríguez-Tovar et al. (2009a) interpreted anoxic conditions
29 459 during deposition of the black radiolaritic shales, with interruptions by short dysaerobic to oxic
30 460 periods as suggested by the occurrence of such ichnotaxa as *Chondrites*, *Planolites*,
31 461 *Thalassinoides* and rare *Zoophycos* in greenish or light grey silicified shales.

32 462

33 463 5.3. Boquerón Member: recovery

34 464

35 465 Foraminiferal assemblages from the Boquerón Member significantly differ from those
36 466 recorded below the OAE2. The lowermost sample of the Boquerón Member only contains

1 467 benthic foraminifera, while planktic foraminifera reappear 26 cm above the base of this
2
3 468 member, where the first occurrence of new species of *Dicarinella* (*D. canaliculata*, *hagni* and
4
5 469 *D. imbricata*) has been observed. *D. algeriana*, a species that has not been recorded in the upper
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7 470 part of the Capas Blancas Member, dominates the assemblages in the lowermost part of the
8
9 471 *Helvetoglobotruncana praehelvetica* Biozone (Fig. 7). The genus *Dicarinella* has been
10
11 472 interpreted as an intermediate-dweller typical of oxygenated mesotrophic environments
12
13 473 (Coccioni and Luciani, 2004; Fig. 5). The assemblages also contain common intermediate to
14
15 474 deep-dweller forms typical of oxygenated, mesotrophic environments such as
16
17 475 *Praeglobotruncana gibba*, *P. stephani* and *Helvetoglobotruncana praehelvetica*. Opportunist
18
19 476 surface-dweller forms typical of oxygenated to poorly oxygenated waters with mesotrophic to
20
21 477 eutrophic conditions are also recorded (e.g., *Hedbergella*, *Whiteinella*, *Guembelitria* and
22
23 478 *Heterohelix*). The opportunistic surface dweller *Whiteinella* progressively proliferated during
24
25 479 the *Helvetoglobotruncana helvetica* Biozone. *Guembelitria* is interpreted as an opportunist
26
27 480 surface-dweller adapted to poorly oxygenated, eutrophic waters (Coccioni and Luciani, 2004;
28
29 481 Reolid et al., 2015) or to variable salinity and nutrient levels (Keller and Pardo, 2004). The
30
31 482 deep-dweller specialists (*Rotalipora*, *Thalmaninella*) are definitively extinct and there are no
32
33 483 genera occupying this ecologic niche (Fig. 7).

34
35 484 Diversity values of benthic foraminifera are lower than in the Capas Blancas Member.
36
37 485 Assemblages are dominated by opportunistic species of the genera *Praebulimina*,
38
39 486 *Gyroidinoides*, *Tappanina* and *Pleurostomella* (e.g., Peryt and Lamolda, 1996). The clear
40
41 487 dominance of *Praebulimina* spp. immediately above the extinction interval suggests that they
42
43 488 may have behaved as disaster species (Peryt and Lamolda, 1996; Reolid et al., 2015).
44
45 489 Buliminids are considered to be indicators of high-food and/or low oxygenation at the seafloor
46
47 490 in the modern oceans (e.g., Fontanier et al., 2002; Gooday, 2003). Some species of
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49 491 *Gyroidinoides* have been interpreted as opportunists (e.g. Peryt and Lamolda, 1996). *Tappanina*
50
51 492 is a biserial, infaunal species that has been reported from dysoxic facies in highly eutrophic
52
53 493 environments (e.g. Eicher and Worstell, 1970; Gustafsson et al., 2003; Friedrich and Erbacher,
54
55 494 2006). Species of *Praebulimina*, *Pleurostomella* and *Tappanina* have been reported from
56
57 495 dysoxic facies in highly eutrophic environments and high organic-matter fluxes (e.g. Eicher and
58
59 496 Worstell, 1970; Coccioni et al., 1993; Widmark, 2000; Gustafsson et al., 2003; Gebhardt et al.,
60
61 497 2004; Friedrich and Erbacher, 2006; Friedrich et al., 2009; Reolid et al., 2015). Moreover, the
62
63 498 dominance of infaunal taxa in the Boquerón Member supports the interpretation of eutrophic
64
65 499 and low oxygen conditions at the seafloor (Jorissen et al., 1995). Similarly, dysoxic conditions
500
501 500 have also been inferred from infaunal-dominated assemblages immediately above the OAE2
event in the Spanish Menoyo section (Peryt and Lamolda, 1996).

1 502 In contrast, redox proxies do not indicate oxygen depleted conditions in the Boquerón
2 503 Member. We conclude that the palaeoenvironmental perturbation related to the OAE2 (recorded
3 504 in the foraminiferal-barren interval of the black radiolaritic shales) induced slow recovery of the
4 505 foraminiferal assemblages, especially affecting benthic foraminifera which display low diversity
5 506 and are dominated by opportunistic species. Detailed analysis of the benthic assemblages shows
6 507 a succession of abundance peaks that represent the first stages of seafloor recolonization after
7 508 the OAE2, which correspond to the ecological replacement of mainly opportunistic foraminifera
8 509 (abundance peaks of *Gyroidinoides beisseli* and *Stensioeina exsculpta* in BH-81, followed by
9 510 peaks of *Praebulimina* sp. and *Gyroidinoides globosus* in BH-83, and *Tappanina* and
10 511 *Pleurostomella* in BH-87). The first colonizers were epifaunal forms, and these were followed
11 512 by peaks of infaunal opportunists, indicating the persistence of adverse conditions at the
12 513 seafloor.

13 514 The first stages of seafloor recolonization by benthic foraminifera occurred previous to
14 515 the water column colonization by planktic forms, mainly by intermediate to deep-dwellers
15 516 typical of mesotrophic to oligotrophic waters (*Dicarinella algeriana*, *Praeglobotruncana*
16 517 *stephani*, *P. gibba* and *Helvetoglobotruncana praehelvetica*). These data indicate that the
17 518 recovery of environmental conditions began in deep and intermediate waters. However, the
18 519 subsequent proliferation of surface-dweller opportunists (*Whiteinella baltica*, *Hedbergella*
19 520 *delrioensis*, *H. simplex*) adapted to mesotrophic to eutrophic conditions, and the decrease in
20 521 planktic foraminiferal diversity, may indicate the return to poorly oxygenated conditions in the
21 522 water column during the *Helvetoglobotruncana helvetica* Biozonen (Fig. 13).

22 523 According to Rodríguez-Tovar et al. (2009a), trace fossils from the Boquerón Member
23 524 (mainly *Chondrites* and *Planolites*) suggest the recovery to pre-OAE conditions, although they
24 525 identified several intervals with oxygen-depleted conditions.

25 526

26 527 **6. Conclusions**

27 528

28 529 The detailed analysis of foraminiferal assemblages and geochemical proxies from the
29 530 Baños de la Hedionda section (South Iberian Palaeomargin) allowed us to identify the impact of
30 531 the OAE2 in this area of the western Tethys.

31 532 The Capas Blancas Member represents the pre-extinction phase with diverse
32 533 foraminiferal assemblages and a good water-column tiering, with well-oxygenated, oligotrophic
33 534 deep-waters and oxygenated to poorly oxygenated, mesotrophic surface-waters. A minor event
34 535 with dysoxic conditions preceding the OAE2 is indicated by quantitative peaks of benthic
35 536 (*Gavelinella*, *Glomospira* and *Praebulimina*) and planktic (*Hedbergella* and *Heterohelix*)
36 537 opportunists.

1 538 The lack of foraminifera in the black radiolaritic shales (*Whiteinella archaeocretacea*
2 539 Biozone), points to adverse conditions. Planktic foraminifera, mainly surface-dweller
3 540 opportunists, are only recorded in the lowermost centimeters of the black shales. The
4 541 enhancement in redox sensitive elements (Cr/Al, V/Al, U/Th, Mo_{EF}, Mo_{aut}, U_{EF} and U_{aut}) and
5 542 increased TOC values point to depleted oxygen conditions. The increase in P/Ti values at the
6 543 base of this stratigraphic interval indicates an abrupt increase in productivity. Therefore, the
7 544 initial increase in opportunist planktic foraminifera typical of poorly oxygenated environments
8 545 and eutrophic conditions, and the disappearance of deep-dweller specialists (e.g. *Rotalipora*)
9 546 and benthic forms is congruent with the debut of the OAE2 as well as with the high redox and
10 547 palaeoproductivity proxies. High concentrations of radiolarians indicate abnormally high
11 548 surface productivity probably related to changes in oceanic circulation and enhanced upwelling
12 549 currents, as well as subsequent shallowing of the oxygen-minimum zone. The increase in Mo_{EF}
13 550 and Mo_{aut} indicates a decrease in oxygen availability towards euxinia in the upper part of the
14 551 black radiolaritic shales.

15 552 The first centimeters of the Boquerón Member (*Helvetoglobotruncana helvetica*
16 553 Biozone) only contain benthic foraminifera, while planktic forms reappear 26 cm above the base
17 554 of this member. Foraminiferal assemblages are less diverse than in the Capas Blancas Member.
18 555 Planktic foraminifera are represented by intermediate-dwellers typical of oxygenated
19 556 mesotrophic environments and opportunist surface dwellers typical of oxygenated to poorly
20 557 oxygenated waters with mesotrophic to eutrophic conditions. Benthic assemblages are
21 558 dominated by opportunistic species that indicate dysoxic conditions above the OAE2 event.

22 559 The palaeoenvironmental perturbation related to the OAE2 induced slow recovery of
23 560 the foraminiferal assemblages, especially affecting benthic foraminifera which display low
24 561 diversity and are dominated by opportunistic species. However, the first stages of seafloor
25 562 recolonization by benthic foraminifera occurred previous to the water column colonization by
26 563 planktic forms, mainly by intermediate to deep-dwellers typical of mesotrophic to oligotrophic
27 564 waters. These data indicate that the recovery of environmental conditions began in deep and
28 565 intermediate waters. The subsequent proliferation of surface-dweller opportunists adapted to
29 566 mesotrophic to eutrophic conditions, and the decrease in planktic foraminiferal diversity, may
30 567 indicate the return to poorly oxygenated conditions in the water column.

31 568
32 569

33 570 **Acknowledgements**

34 571
35 572 We thank Agustín Martín Algarra (Universidad de Granada) and Luis O'Dogherty
36 573 (Universidad de Cádiz) for priceless collaboration during the sampling campaign. This study

1 574 has been conducted within the framework of the Projects CGL2011-23077, CGL2011-22912,
2 575 CGL2012-33281 and RYC-2009-04316 of the Spanish Ministry of Science and Technology
3
4 576 (FEDER funds), P11-RNM-7408 (Junta de Andalucía), and the Consolidated Group E05 funded
5
6 577 by the Government of Aragón. Sánchez-Quiñónez, C.A. thanks the Fundación Carolina (Spain)
7
8 578 for financial support during this research stay at Zaragoza University.
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- 50 848
- 51 849
- 52 850

54 851 **Appendix 1. Planktic foraminiferal species**

56 852

57 853 *Dicarinella algeriana* (Caron, 1966)

58 854 *Dicarinella canaliculata* (Reuss, 1854)

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- 1 855 *Dicarinella hagni* (Scheibnerova, 1962)
2
3 856 *Dicarinella imbricata* (Mornod, 1950)
4
5 857 *Globigerinelloides bentonensis* (Morrow, 1934)
6
7 858 *Globigerinelloides ultramicrus* (Subbotina, 1949)
8
9 859 *Globoheterohelix paraglobulosa* Georgescu & Huber, 2009
10
11 860 *Guembelitria cenomana* (Keller, 1935)
12
13 861 *Hedbergella delrioensis* (Carsey, 1926)
14
15 862 *Hedbergella planispira* (Tappan, 1940)
16
17 863 *Hedbergella simplex* (Morrow, 1934)
18
19 864 *Helvetoglobotruncana helvetica* (Bolli, 1945)
20
21 865 *Helvetoglobotruncana praehelvetica* (Trujillo, 1960)
22
23 866 *Heterohelix moremani* (Cushman, 1938)
24
25 867 *Heterohelix reussi* (Cushman, 1938)
26
27 868 *Marginotruncana marginata* (Reuss, 1845)
28
29 869 *Marginotruncana sigali* (Reichel, 1950)
30
31 870 *Parathalmanninella appenninica* (Renz, 1936)
32
33 871 *Praeglobotruncana delrioensis* (Plummer, 1931)
34
35 872 *Praeglobotruncana gibba* Klaus, 1960
36
37 873 *Praeglobotruncana stephani* (Gandolfi, 1942)
38
39 874 *Rotalipora cushmani* (Morrow, 1934)
40
41 875 *Rotalipora monsalvensis* (Mornod, 1950)
42
43 876 *Schackoina cenomana* (Shacko, 1897)
44
45 877 *Sigalitruncana marianosi* (Douglas, 1969)
46
47 878 *Thalmanninella brotzeni* Sigal, 1948
48
49 879 *Thalmanninella deecke* (Franke, 1925)
50
51 880 *Thalmanninella greenhornensis* (Morrow, 1934)
52
53 881 *Whiteinella aprica* (Loeblich & Tappan, 1961)
54
55 882 *Whiteinella archaeocretacea* Pesagno, 1967
56
57 883 *Whiteinella aumalensis* (Sigal, 1952)
58
59 884 *Whiteinella baltica* Douglas and Rankin, 1969
60
61 885 *Whiteinella brittonensis* (Loeblich and Tappan, 1961)
62
63 886 *Whiteinella inornata* (Bolli, 1957)
64
65 887
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67 888 **Appendix 2. Benthic foraminiferal species**
68
69 889
70
71 890 *Ammodiscus* spp.

- 1 891 *Aragonia* sp.
2
3 892 *Ammosphaeroidina* spp.
4
5 893 *Arenobulimina* spp.
6
7 894 *Astacolus crepidularis* (Roemer, 1842)
8
9 895 *Astacolus gratus* (Reuss, 1863)
10
11 896 *Astacolus* spp.
12
13 897 *Bathysiphon* spp.
14
15 898 *Charltonina australis* Scheibnerová, 1978
16
17 899 *Charltonina* sp.
18
19 900 *Clavulinoides* sp.
20
21 901 *Conorotalites* sp.
22
23 902 *Coryphostoma* spp.
24
25 903 *Dorothia pupa* (Reuss, 1860)
26
27 904 *Dorothia* spp.
28
29 905 *Ellipsoidella* sp.
30
31 906 *Ellipsodimorphina* sp.
32
33 907 *Epistomina* sp.
34
35 908 *Epistomina spinulifera* (Reuss, 1862)
36
37 909 *Fronicularia* sp.
38
39 910 *Gaudryina pyramidata* Cushman, 1926
40
41 911 *Gaudryina* spp.
42
43 912 *Gavelinella cenomanica* (Brotzen, 1945)
44
45 913 *Gavelinella* spp.
46
47 914 *Glandulina* sp.
48
49 915 *Globorotalites* sp.
50
51 916 *Globulina* sp.
52
53 917 *Glomospira* spp.
54
55 918 *Glomospirella* sp.
56
57 919 *Gubkinella graysonensis* (Tappan, 1940)
58
59 920 *Gyroidinoides beisseli* (White, 1928)
60
61 921 *Gyroidinoides globosus* (Hagenow, 1842)
62
63 922 *Gyroidinoides* sp.
64
65 923 *Gyroidinoides subglobosus* Dailey, 1970
66
67 924 *Hemirobulina* sp.
68
69 925 *Hyperammia* sp.
70
71 926 *Laevidentalina* spp.

- 1 927 *Lagena* sp.
2
3 928 *Lenticulina rotulata* (Lamarck, 1804)
4
5 929 *Lenticulina* spp.
6
7 930 *Lenticulina truncata* (Reuss, 1851)
8
9 931 *Lingulina* sp.
10
11 932 *Marginulina* sp.
12
13 933 *Marginulinopsis* sp.
14
15 934 *Marssonella oxycona* (Reuss, 1860)
16
17 935 *Oolina* spp.
18
19 936 *Patellina* sp.
20
21 937 *Plectina pinswangensis* Hagn, 1953
22
23 938 *Pleurostomella* spp.
24
25 939 *Praebulimina* spp.
26
27 940 *Pyrulina* spp.
28
29 941 *Pyrulinoidea* spp.
30
31 942 *Quadrimorphina* sp.
32
33 943 *Ramulina* spp.
34
35 944 *Rhabdammina* sp.
36
37 945 *Saracenaria* sp.
38
39 946 *Spiroplectammina roemeri* Lalicker, 1935
40
41 947 *Spiroplectammina* sp.
42
43 948 *Spiroplectammina spectabilis* (Grzybowski, 1898)
44
45 949 *Stensioeina exsculpta* (Reuss, 1860)
46
47 950 *Stensioeina granulata* (Olbertz, 1942)
48
49 951 *Stensioeina* sp.
50
51 952 *Tappanina selmensis* (Cushman, 1933)
52
53 953 *Tappanina* sp.
54
55 954 *Textularia* sp.
56
57 955 *Tristix* sp.
58
59 956 *Tritaxia gaultina* (Morozova, 1948)
60
61 957 *Vaginulinopsis* sp.
62
63 958 *Valvulineria* sp.
64
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69 961 **Figure caption.**
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71 962

1 963 **Fig. 1.** (a) Geological setting of the Betic Cordillera, (b) detailed geological setting of the
 2 964 studied section (star) close to Manilva village, (c) Baños de la Hedionda section including
 3 965 the lithostratigraphic units, foraminiferal biozones and location of the samples.

6 966 **Fig. 2.** Macroscopic view of the differentiated lithostratigraphic units and the respective
 7 967 microfacies. Capas Blancas Member (a) and (b), black radiolaritic shales (c) and (d), and
 8 968 Boquerón Member (e) and (f). Scale bar 1 mm.

11 969 **Fig. 3.** Planktic foraminiferal species in the Los Baños de la Hedionda section: **1-2** *Rotalipora*
 12 970 *monsalvensis* (BH-0). **3-4** *Parthammanninella appenninica* (BH-5, BH-7). **5**
 13 971 *Marginotruncana* sp. (BH-17). **6** *Whiteinella archaeocretacea* (BH-17). **7**
 14 972 *Praeglobotruncana delrioensis* (BH-40). **8-9** *Praeglobotruncana gibba* (BH-45). **10-11**
 15 973 *Dicarinella hagni* (BH-83). **12** *Dicarinella algeriana* (BH-83). **13** *Dicarinella imbricata*
 16 974 (BH-83). **14** *Dicarinella canaliculata* (BH-83). **15** *Shackoina cenomana* (BH-83). **16-17**
 17 975 *Guembelitria cenomana* (BH-83). **18** *Dicarinella* sp. (BH-89). **19-20**
 18 976 *Helvetoglobotruncana helvetica* (BH-89). **21** *Marginotruncana marginata* (BH-89). **22- 23**
 19 977 *Dicarinella hagni* (BH-89). Scale bars: 0.1 mm.

26 978 **Fig. 4.** Stratigraphic distribution of planktic/benthic ratio (P/B) and diversity of planktic and
 27 979 benthic foraminifera.

29 980 **Fig. 5.** Planktic foraminiferal morphogroups and inferred life style including redox and trophic
 30 981 requirements based on Hart and Bailey (1979), Hart (1999), Keller et al. (2001), Coccioni
 31 982 and Luciani (2004) and Reolid et al. (2015).

34 983 **Fig. 6.** Stratigraphic distribution of planktic foraminiferal morfogroups.

36 984 **Fig. 7.** Stratigraphic distribution of planktic foraminiferal taxa.

38 985 **Fig. 8.** Benthic foraminiferal species in the Los Baños de la Hedionda section: **1**
 39 986 *Spiroplectammmina roemeri* (BH-0). **2** *Plectina pinswagensis* (BH-0). **3** *Ammodiscus* sp.
 40 987 (BH-0). **4** *Arenobulimina* sp. (BH-0). **5** *Lingulina* sp. (BH-0). **6** *Saracenaria* sp. (BH-0). **7**
 41 988 *Hemirobulina* sp. (BH-0). **8** *Tristix* sp. (BH-0). **9** *Stensioeina exsculpta*. **10-11** *Charltonina*
 42 989 *australis* (BH-0). **12** *Bolivinopsis spectabilis* (BH-1). **13** *Ammosphaeroidina* sp. (BH-1). **14**
 43 990 *Gaudryina pyramidata* (BH-3). **15-16-17** *Gyroidinoides globosus* (BH-18). **18**
 44 991 *Gyroidinoides beisseli* (BH-18). **19-20** *Valvulineria* sp. (BH-24). **21-22** *Globorotalites* sp.
 45 992 (BH-25). **23-24** *Gyroidinoides subglobosus* (BH-88). Scale bars: 0.1 mm.

51 993 **Fig. 9.** Stratigraphic distribution of selected benthic foraminiferal species.

53 994 **Fig. 10.** Stratigraphic distribution of benthic foraminifera according to the inferred microhabitat.

54 995 **Fig. 11.** Stratigraphic fluctuations of geochemical redox proxies and U- and Mo-based proxies
 55 996 (enrichment factor and authigenic content).

58 997 **Fig. 12.** Stratigraphic distribution of CO₃Ca, total sulphur (TS), total organic carbon (TOC), and
 59 998 geochemical palaeoproductivity proxies (Ba/Al and P/Ti ratios).

1 999 **Fig. 13.** Evolution of trophic conditions, productivity and oxygenation in the water column and
2
3 1000 at the seafloor (sea-bottom waters) inferred from foraminiferal assemblages and
4 1001 geochemical proxies.
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Figure 01

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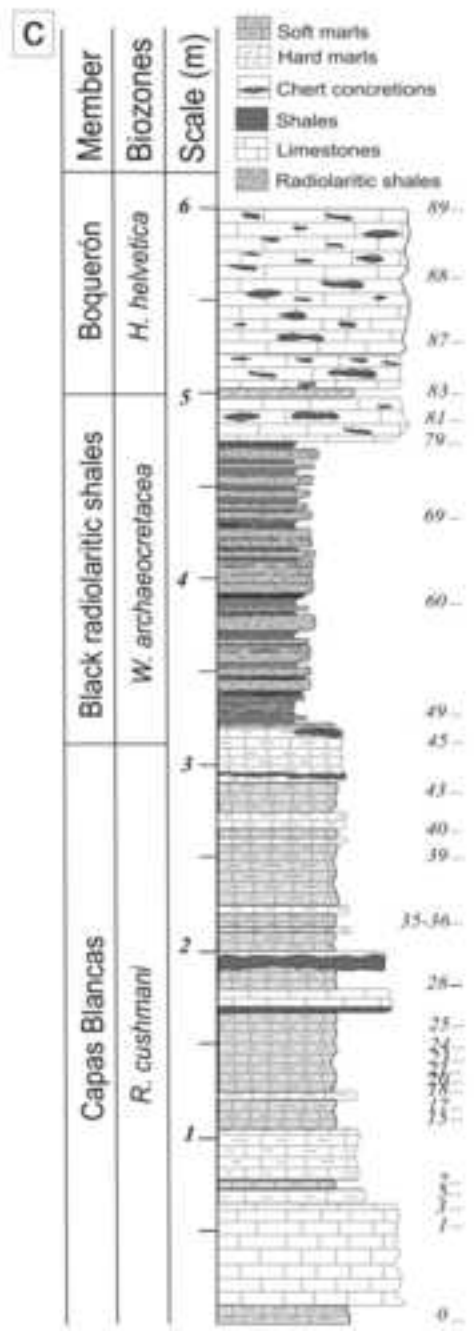
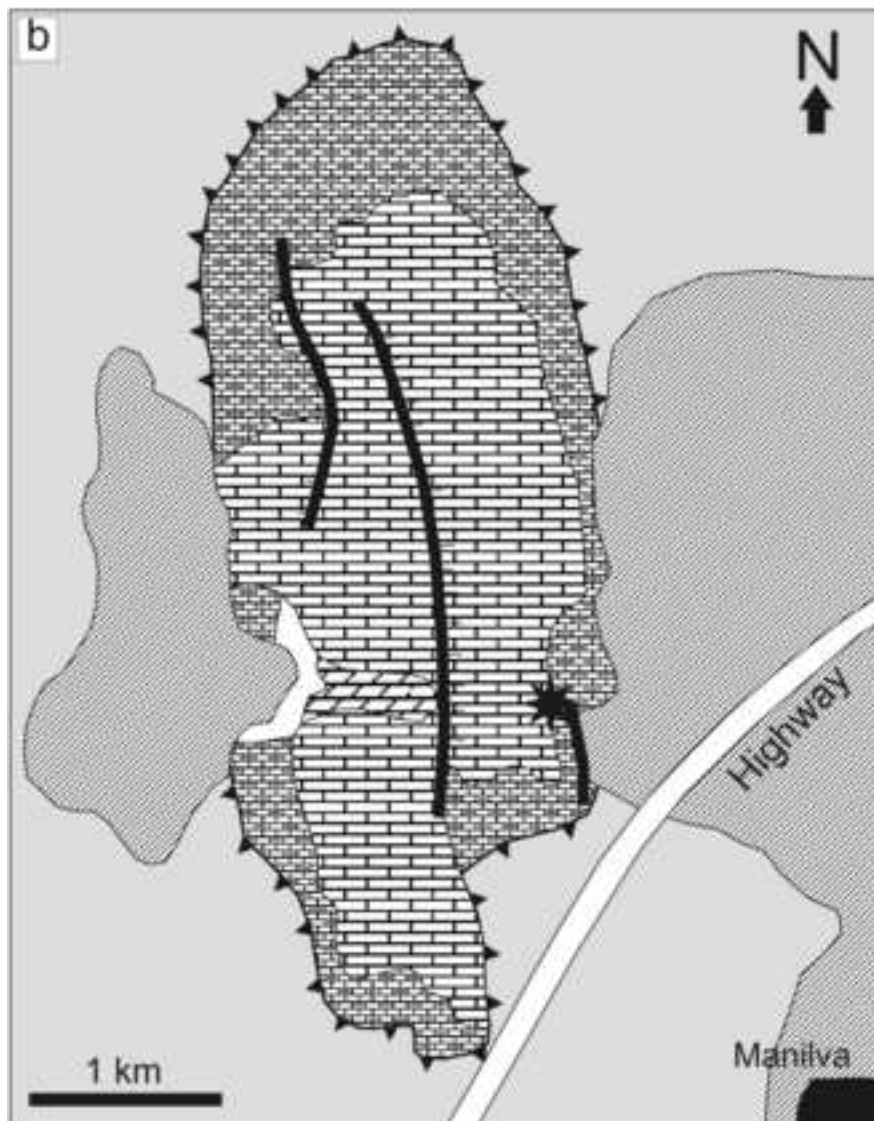
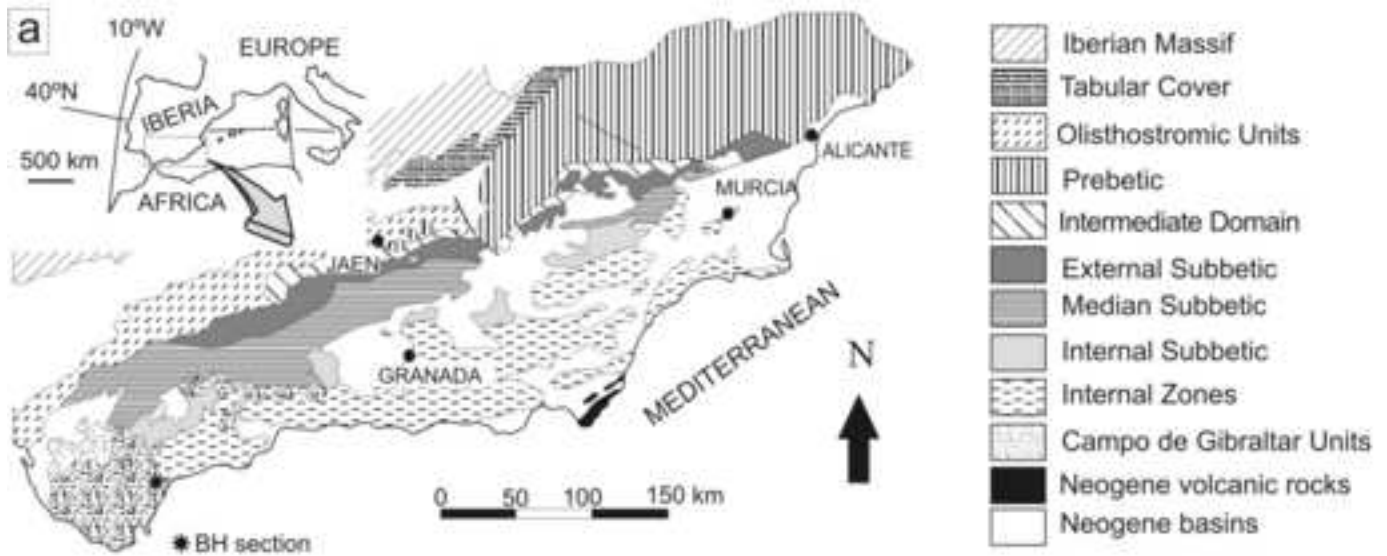


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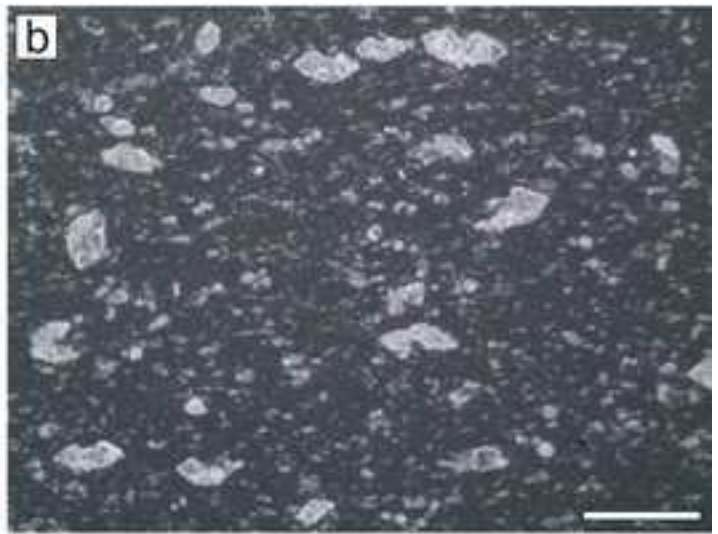


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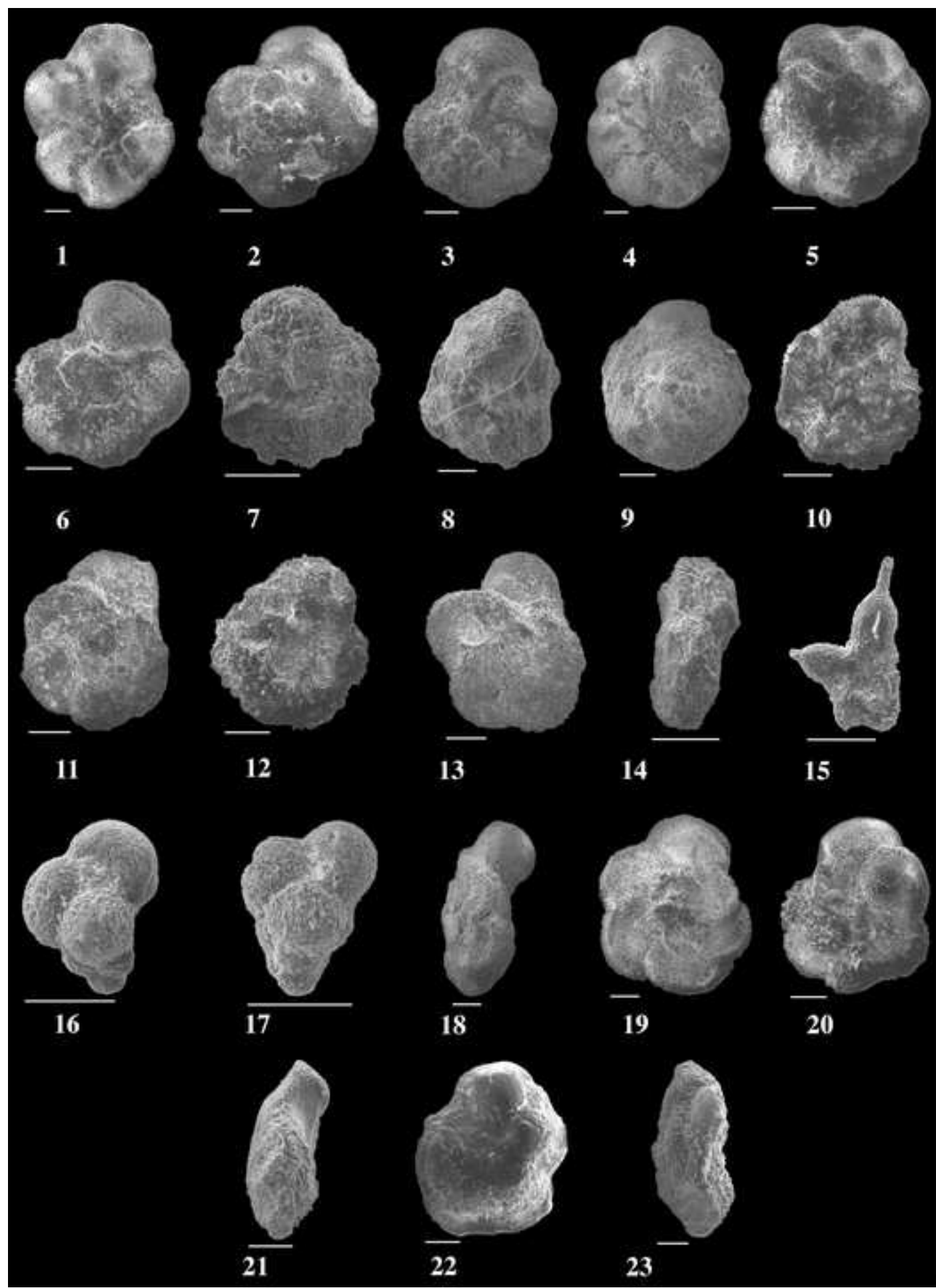


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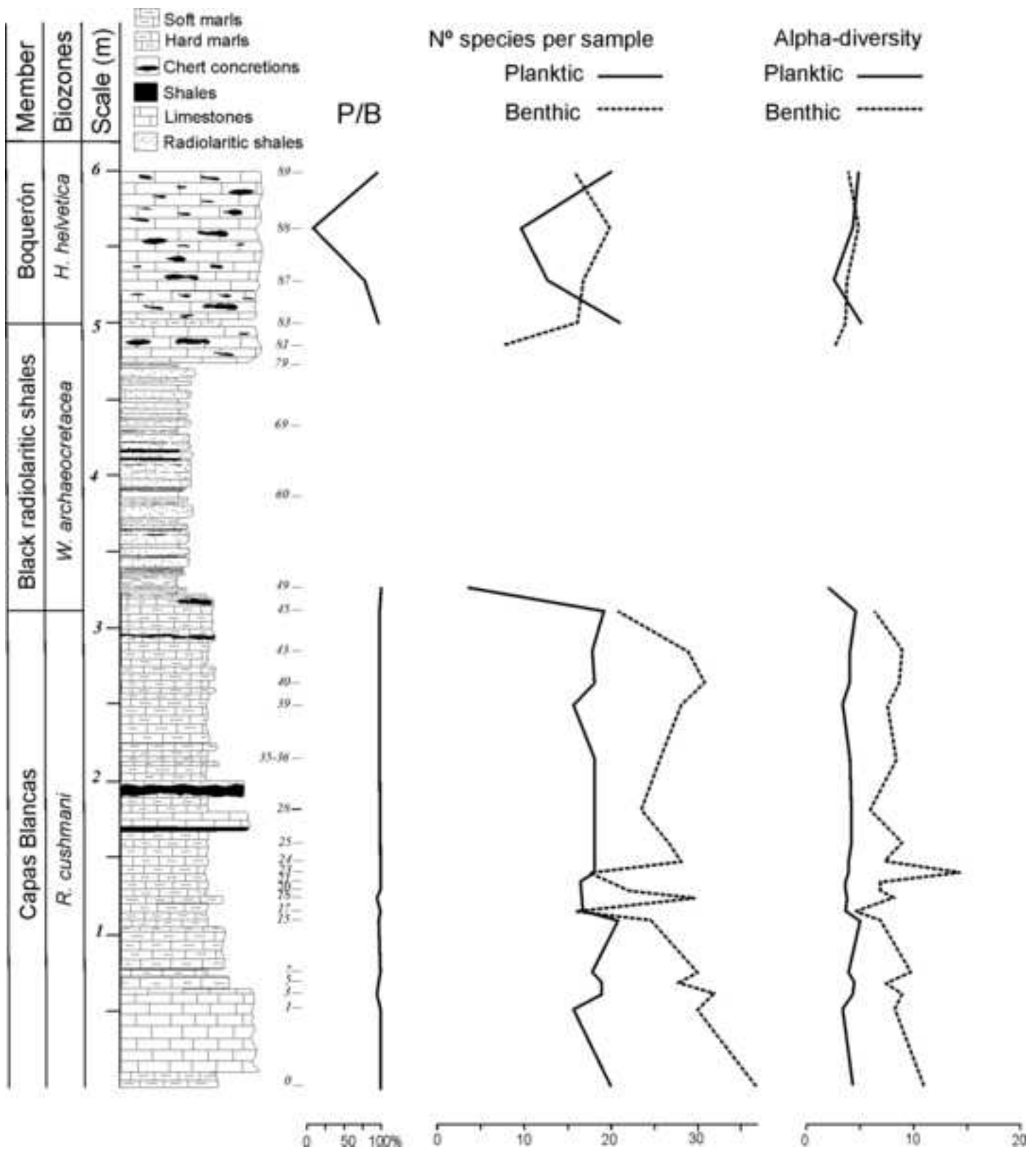


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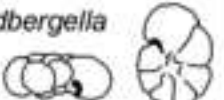

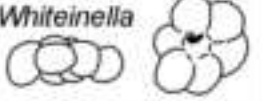



Morphogroup	Genera	Habitat	Strategy	Requirements	
				Oxygenation	Trophic
Strongly keeled trochospiral	<i>Dicarinella</i> 	Intermediate-dweller	Intermediate	Oxygenated	Mesotrophic
	<i>Parathalmanninella</i> <i>Thalmanninella</i> 	Intermediate to deep-dweller	Specialist	Well-oxygenated	Oligotrophic
	<i>Rotalipora</i> 	Intermediate to deep-dweller	Specialist	Well-oxygenated	Oligotrophic
Weakly keeled trochospiral	<i>Helvetoglobotruncana</i> 	Intermediate to deep-dweller	Intermediate to specialist	Oxygenated to well-oxygenated	Oligotrophic to mesotrophic
	<i>Praeglobotruncana</i> <i>Marginotruncana</i> 	Intermediate-dweller	Intermediate	Oxygenated	Mesotrophic
Unkeeled trochospiral	<i>Hedbergella</i> 	Surface-dweller	Opportunist	Oxygenated to poorly-oxygenated	Eutrophic
	<i>Shackoina</i> 	Intermediate-dweller	Intermediate	Oxygenated to poorly-oxygenated	Mesotrophic to eutrophic
	<i>Whiteinella</i> 	Surface-dweller	Opportunist	Oxygenated to poorly-oxygenated	Mesotrophic to eutrophic
Planispiral	<i>Globigerinelloides</i> 	Surface to intermediate-dweller	Opportunist to intermediate	Oxygenated to poorly-oxygenated	Mesotrophic to eutrophic
Biserial	<i>Heterohelix</i> <i>Globoheterohelix</i> 	Surface to intermediate-dweller	Opportunist	Oxygenated to poorly-oxygenated	Eutrophic
Triserial	<i>Guembelitria</i> 	Surface-dweller	Opportunist	Poorly-oxygenated	Eutrophic

Figure 06

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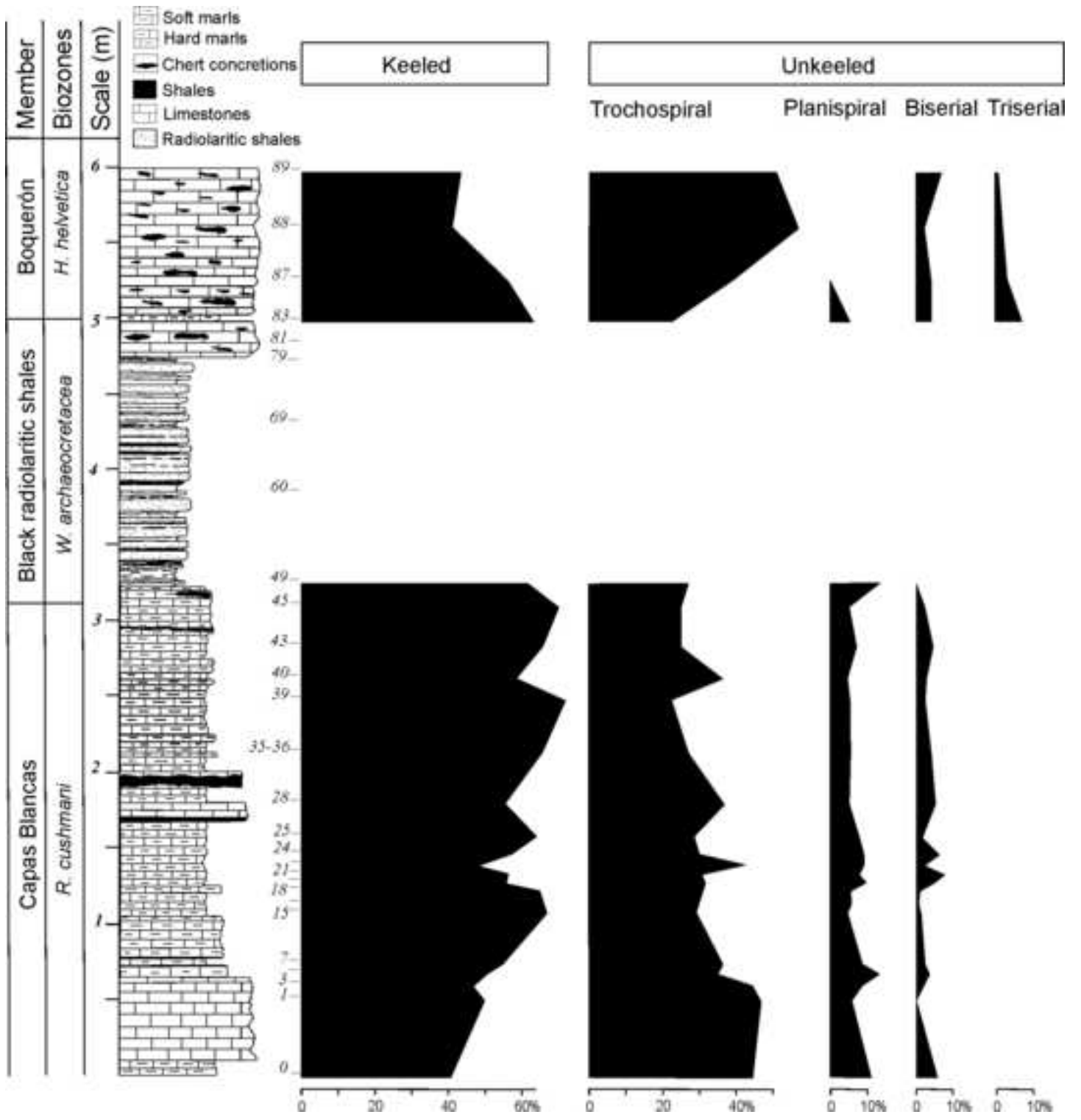


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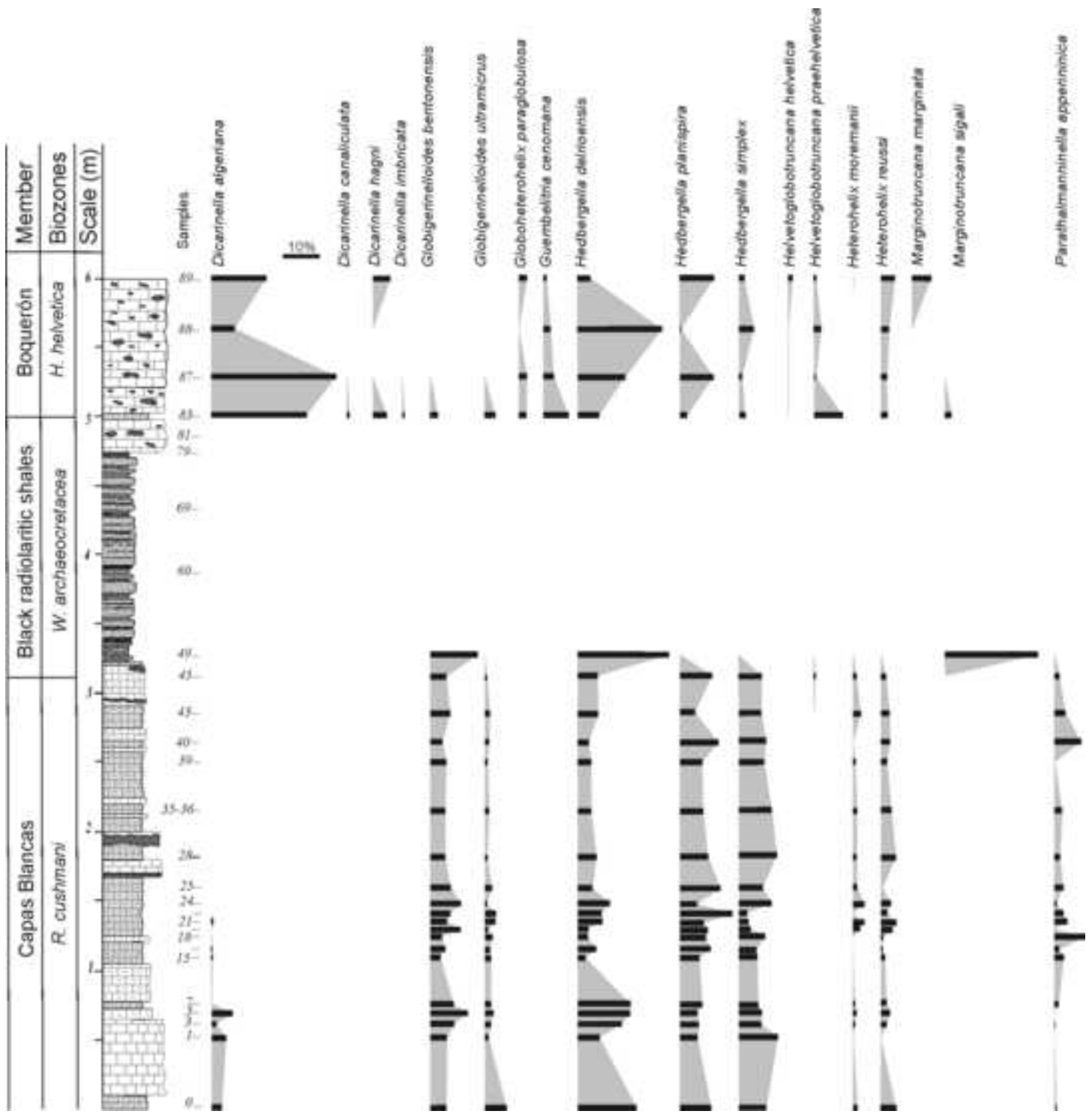


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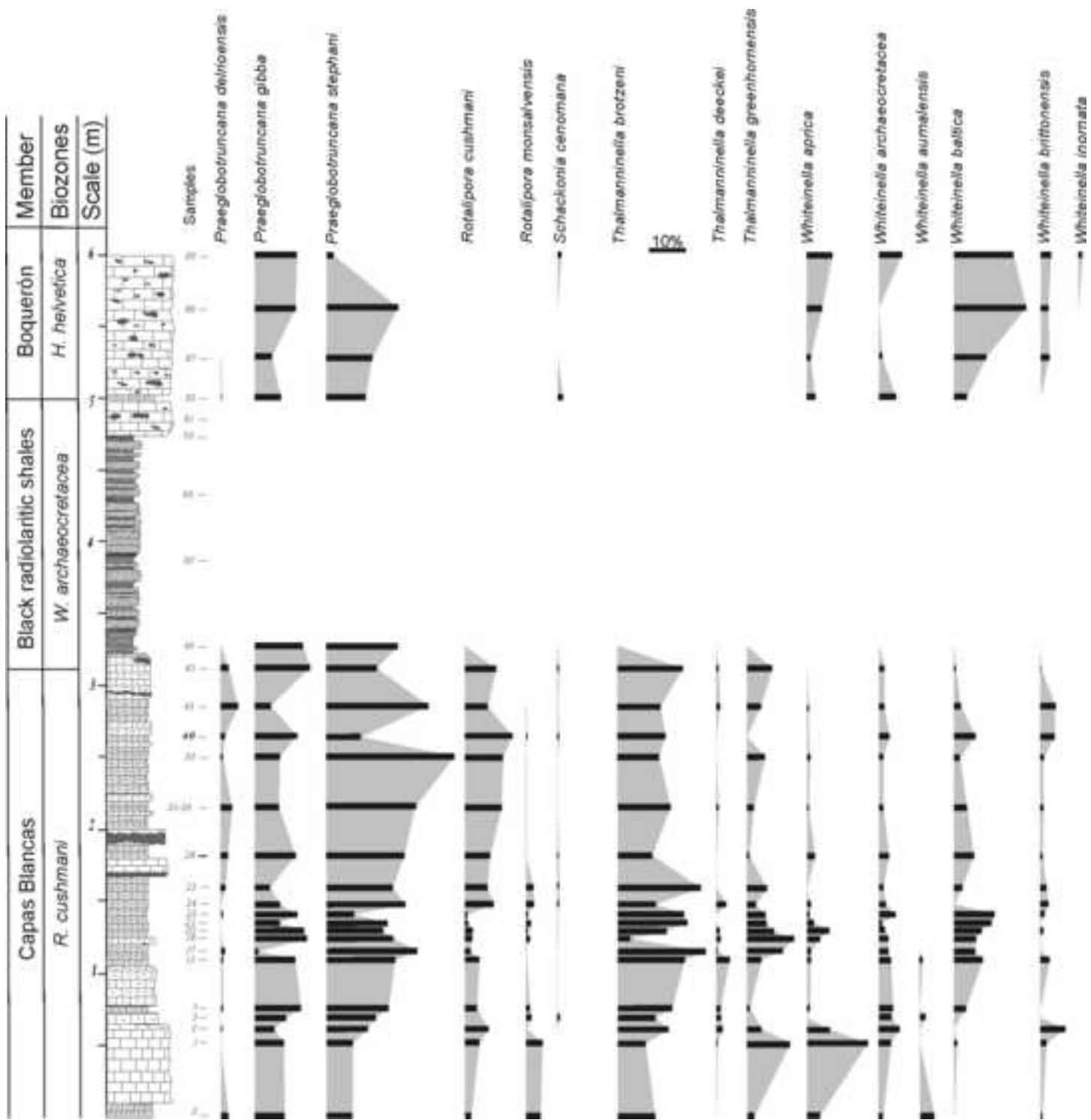


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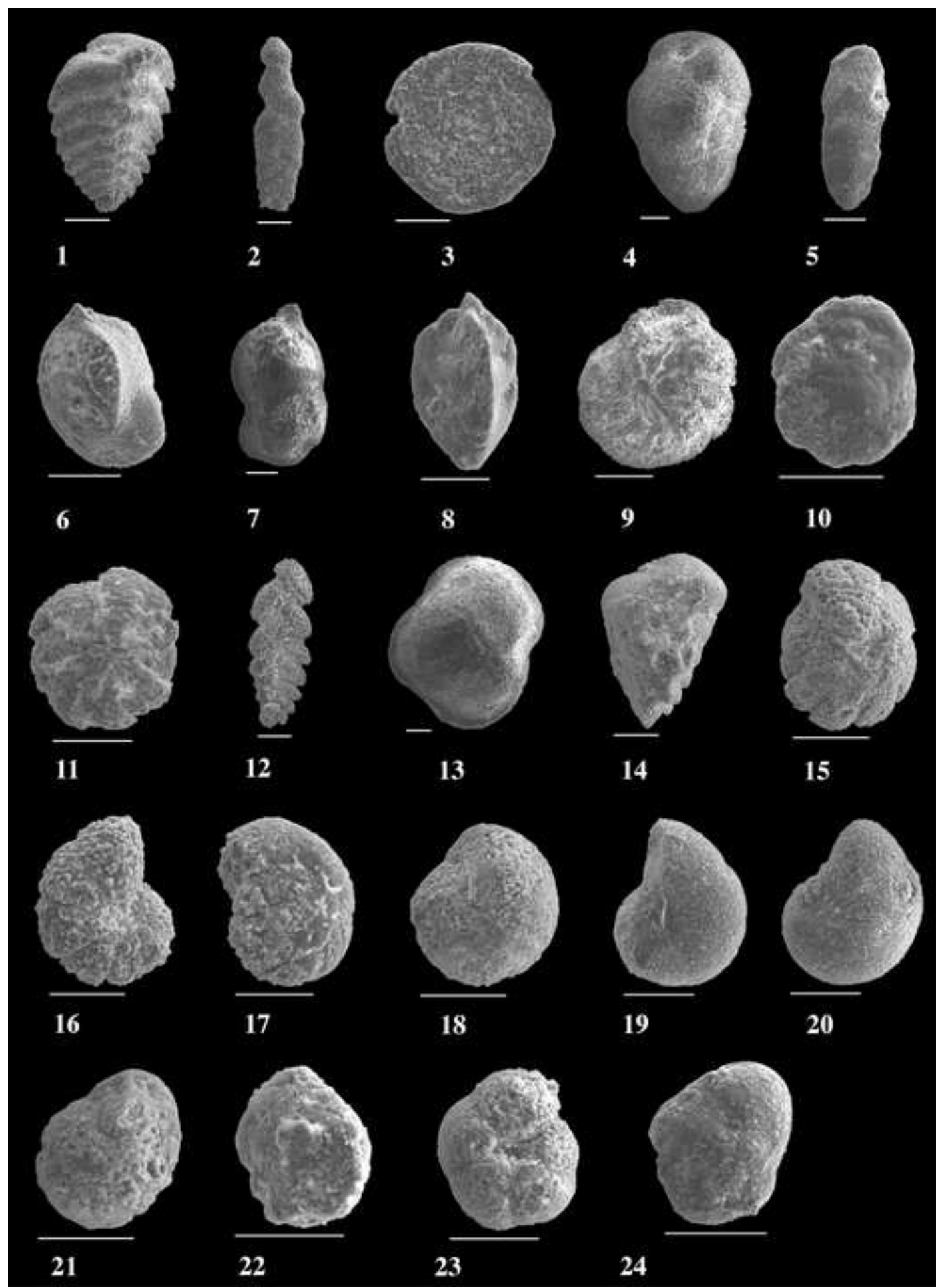


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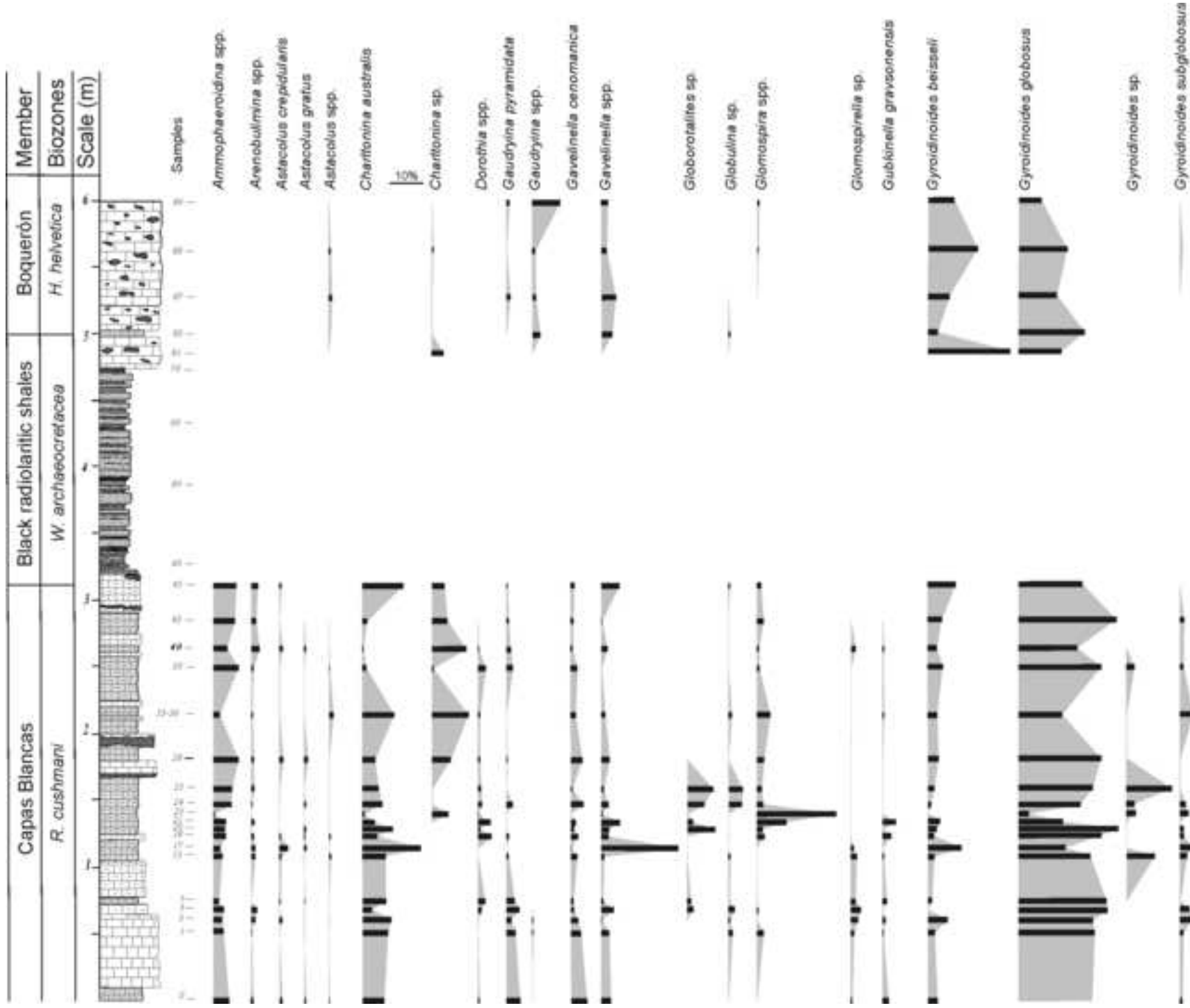


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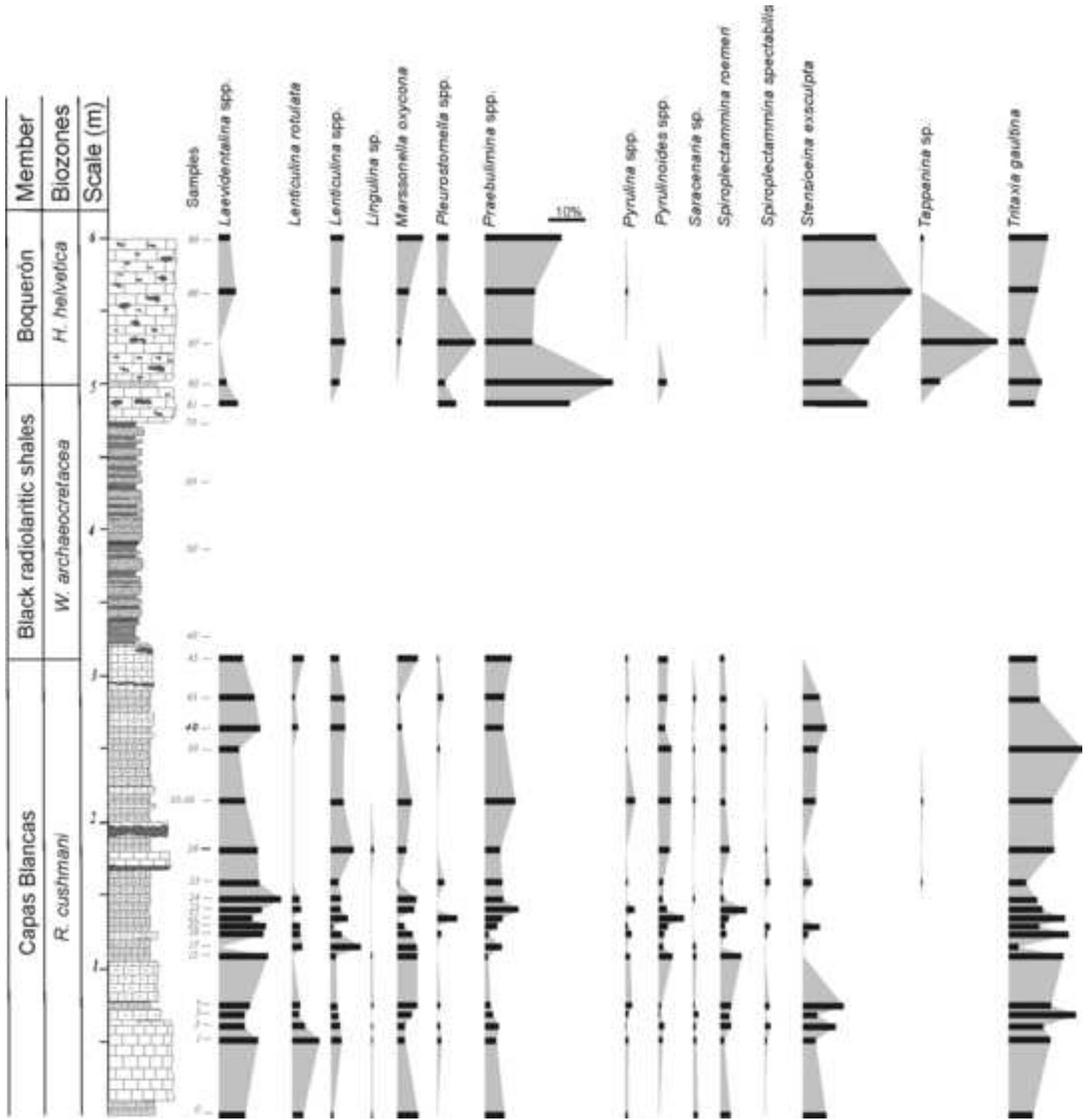


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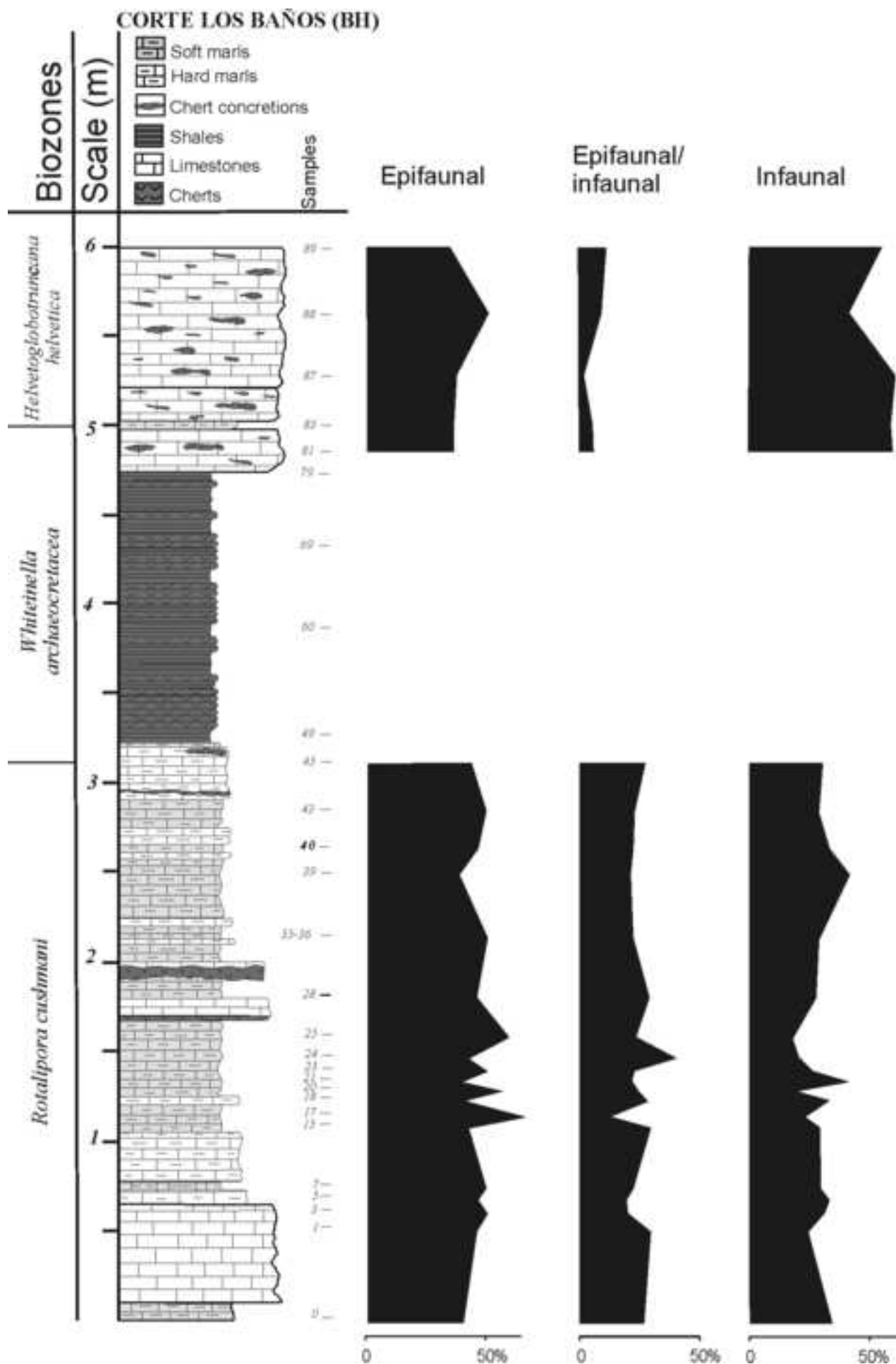


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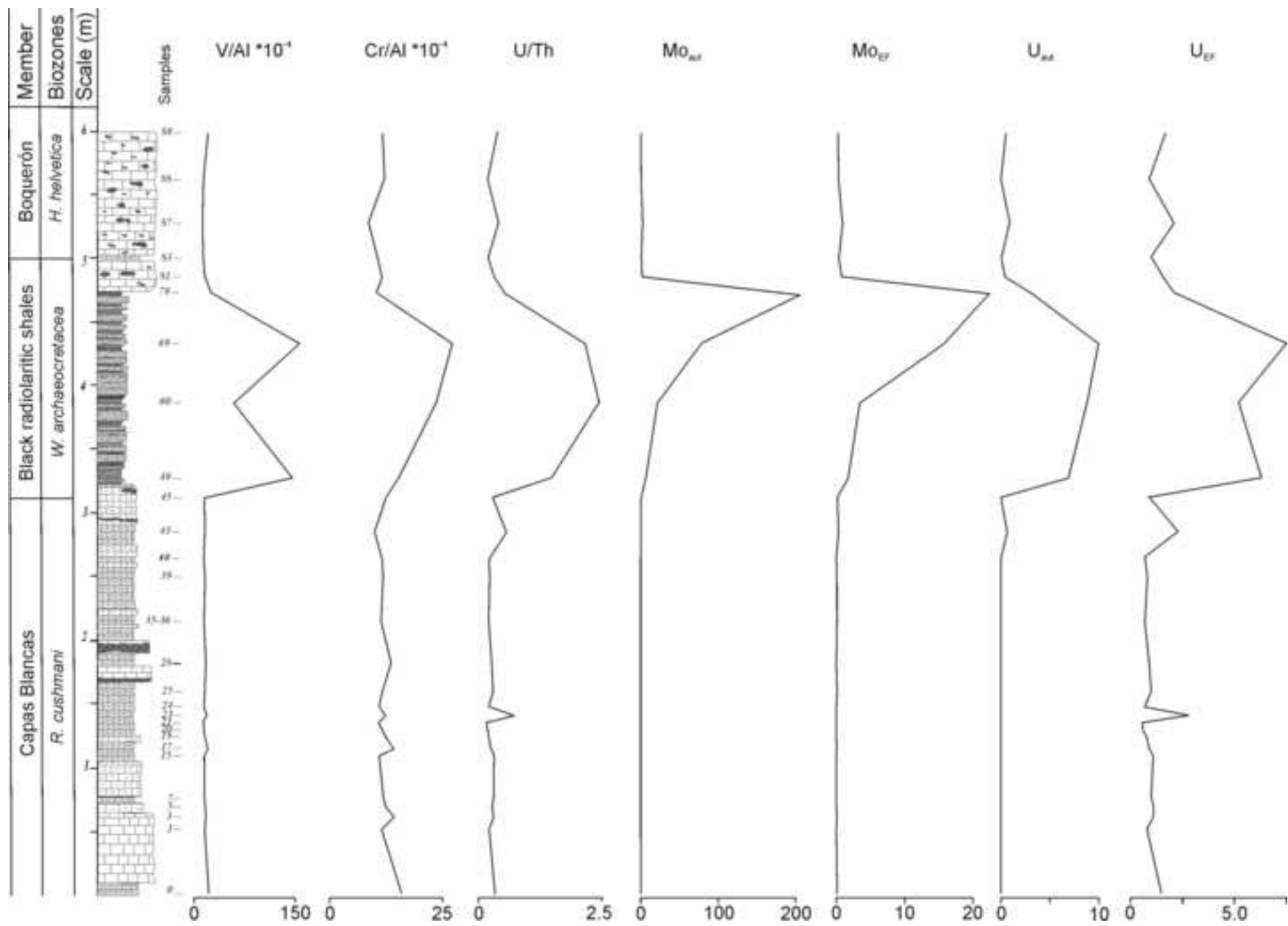


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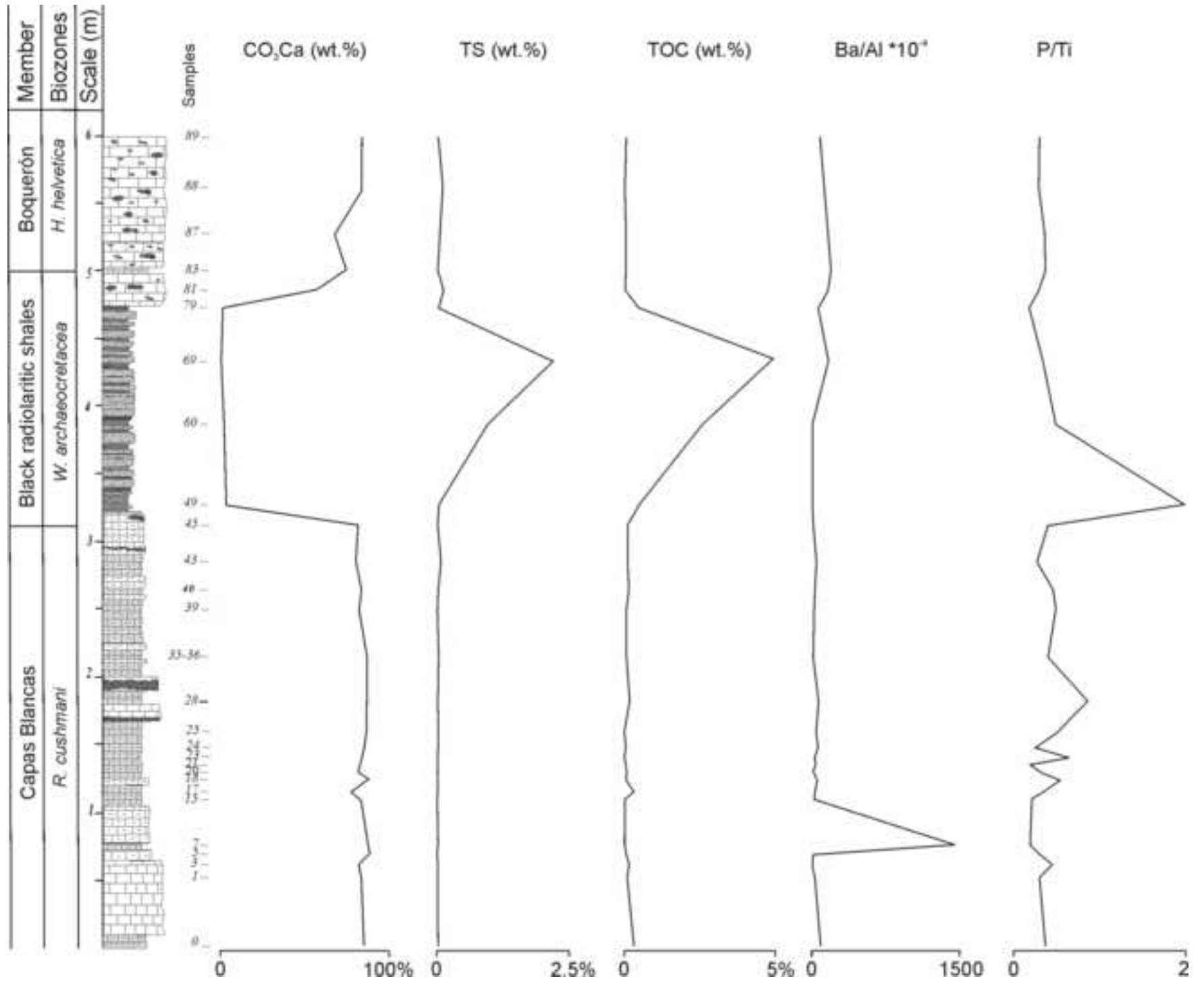


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