High resolution biostratigraphy based on planktic foraminifera across the Cretaceous–Paleogene transition at the Bidart section (SW France)

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ABSTRACT:


Based on high resolution biostratigraphic analysis of planktic foraminifers, it is confirmed that the Bidart section (eastern margin of the Atlantic Ocean) represents a continuous Cretaceous–Paleogene (K-Pg) succession. Nevertheless, the foraminiferal species Plummerita hantkeninoides, regarded as a latest Maastrichtian marker species, is absent and Abathomphalus mayaroensis ranges to the top of the Maastrichtian (= K/Pg boundary). Pseudoguembelina hariaensis is present throughout the succession, and it is proposed herein to substitute Pl. hantkeninoides as the marker of the uppermost Maastrichtian.

At least 53 out of 72 species became suddenly extinct at the K/Pg boundary, defined by the Ir anomaly (Bonté et al. 1984; Delacotte et al. 1982). The extinct species are represented by globotruncanids and large heterohelicids, characteristic of the tropical-subtropical deep photic sea water under the mesotrophic conditions of the Late Maastrichtian. The Lower Danian succession (the zones of Guembelitria cretacea, Parvularugoglobigerina eugubina, Parasubbotina pseudobulloides) is less expanded than at El Kef (Tunisia) [the Global Stratotype Section and Point (GSSP) for the Cretaceous/Paleogene (K/Pg) boundary] or at Ellès (Tunisia) [its auxiliary section].

Key words: Planktic foraminifera; Biostratigraphy; Biozones; Mass extinction; Maastrichtian; Danian; Middle latitude.

INTRODUCTION

Among the planktic foraminifers, the globotruncanids first appeared in the Turonian. During the Late Cretaceous this group underwent a complex evolution and diversification. About one hundred species are listed and described from the Turonian–Maastrichtian and more than ten of them are considered to have highbiostratigraphic potential (Pessagno 1967; Postuma 1971; Robaszynski et al. 1979 and 1983-1984; Peryt 1980; Salaj 1983; Caron 1985; Rami et al. 1997 among others). At the K/Pg boundary, the most severe and catastrophic biological event in the history of our planet, most of the heterohelicids and globotruncanids suffered mass extinctions. This crisis was already signalled in numerous older studies on foraminifers (Luterbacher and Premoli Silva 1964; Bolli 1966; Salaj 1983; Berggren and Norris 1997 among others), but became better doc-
umented with the advent of the high resolution approach to biostratigraphy and the application of quantitative analysis (Smit 1982; Keller 1988; Canudo et al. 1991; Molina et al. 1996; Olsson et al. 1992; Olson and Liu 1993; Olsson et al. 1999; Zaghbib-Turki et al. 2000 among others).

After the K/Pg crisis, the globotruncanids were replaced by the appearance and an “explosive” adaptive radiation of small globigerinids.

The planktic foraminiferal zonations and biochronology of the Upper Maastrichtian–Lower Danian of the middle and lower latitudes is still hotly debated (Text-fig. 5) (Smit 1982; Toumarkine and Luterbacher 1985; Keller 1988; Berggren et al. 1995; Olsson et al. 1999; Molina et al. 1996; Arenillas et al. 2004 among others). Whereas the Abathomphalus mayaroensis Zone is used as a standard subdivision in the Upper Maastrichtian, the proposed Danian zonation is still highly controversial. The suggested evolutionary pattern and diversification of planktic foraminifers across the K/Pg boundary interval depends on sampling resolution and the taxonomy of the early globigerinids that originated at the base of the Danian.

This paper presents the high resolution biostratigraphy of the K/Pg boundary interval of the Bidart section and discusses its contribution to the general discussion on the standard biozonation of the uppermost Maastrichtian and Danian (Bolli 1966; Berggren 1971; Blow 1979; Smit 1982; Caron 1985; Toumarkine and Luter-

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**MATERIAL AND METHODS**

The Bidart section is located in south-western France, within the Basque-Pyrenean Basin between the villages of Hendaye and Biarritz, ca. 2 km north of the village of Bidart, where the Upper Cretaceous–Eocene succession is well exposed along the beaches of Bidart [latitude 43° 27' N and longitude 1° 35' E; Text-figs 1 A, B, C]. The section is readily accessible from the N10 National Road.

The uppermost Maastrichtian in the Bidart section (Text-fig. 3A), consist of alternations of metre-thick marls and argillaceous limestones with abundant foraminifers and scarce echinoids. The uppermost 2 cm

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Text-fig. 1 Geographical (A–B) and Paleogeographical setting (C) of the Bidart section located in the Pyrenean domain during the Paleocene (from Pujalte et al. 1994)
of the Maastrichtian are grey soft marls. The K/Pg boundary is marked by a 2 mm thick rusty layer. The lowermost Danian consists of 6 cm-thick dark boundary clays. The overlying sediments consist of brownish clays and thin laminated dark grey marls and pink and white limestones. The base of these limestones is erosive, and their coarse texture (i.e. grainstone) and the breccia feature observed between 1.6 m and 2.10 m above the K/Pg boundary rusty layer suggest a mass flow deposit.

The deposits below and above the K/Pg boundary layer contrast sharply (Text-fig. 3B). Those of the uppermost Maastrichtian are grey marls and those of the lowermost Danian (6 cm-thick) are dark clays. The K/Pg boundary layer is marked by a positive Ir anomaly (Smit and Ten Kate 1982; Bonté et al. 1984; Rocchia et al. 1987) and Ni-spinel enrichment (Robin and Rocchia 1998).

For the foraminiferal studies reported herein, nineteen samples were taken across a 7.60 m-thick boundary interval; eight samples across the 4 m-thick part of the uppermost Maastrichtian (samples B-400 cm to B-0-2 cm, below the boundary) and eleven samples across the 3.60 m-thick interval of the lower Danian (samples B 0-2 cm to B 360 cm above the boundary) (see Text-figs 2 A, B and Text-fig. 3A, B). Close to the K/Pg boundary the samples were taken at intervals of 2 to 10 cm. Further below and above the K/Pg boundary, the samples were taken at 30 cm intervals. The preservation of the planktic foraminifers is generally good.

The samples from the soft clayey or marly deposits were disaggregated in water with H$_2$O$_2$; the limestone samples were soaked in dilute acetic acid (80%) for 6 hours and then washed through a 63 µm sieve. All of the samples were dried at 50°C.

**BIOSTRATIGRAPHY**

Four biozones can be recognized in the interval of the Bidart section studied (Text-figs 4, 5):

The *Abathomphalus mayaroensis* Total Range Zone: The zone is defined by the range of the nominative taxon (Bolli 1966) (Text-fig. 5) and has been widely recognized in the Tethyan area and elsewhere (Pessagno 1969; Postuma 1971; Premoli Silva and Bolli 1973; Sigal 1977; Robaszynski et al. 1983-1984; Smit 1982; Caron 1985; Blow 1979; Huber 1991; Canudo et al. 1991, Arz et al. 2000; Molina et al. 1996; Arz et al. 1998; Arenillas et al. 1996, 1998; Arz et al. 1999; Arz et al. 1998, Zaghbib-Turki et al. 2000 and 2001; Karoui-Yaakoub et al. 2002; Zaghbib-Turki and Karoui-Yaakoub 2004). In the samples studied the nominative taxon is scarce, albeit it ranges to the top of the Maastrichtian. This observation corresponds well to the rare occurrences noted in the topmost Maastrichtian elsewhere, including the El Kef (Tunisia) K/Pg boundary stratotype and auxiliary sections (Schmitz et al. 1992; Arenillas et al. 2000; Zaghbib-Turki et al. 2000; Zaghbib-Turki and Karoui-Yaakoub 2004; Molina et al. 2006). The thickness of the entire biozone in the Basque–Pyrenean Basin is usually about 100 m.

Missing from the section studied is *Plummerita hantkeninoides* (see Molina et al. 1998; Arz et al. 1999), a small-sized species (< 150 µm), used formerly as an indicator of the latest Maastrichtian, and the index of the eponymous latest Maastrichtian foraminiferal zone (Canudo et al. 1991; Keller et al. 1995). However, it was shown that the species is generally missing from high latitude areas (sites 738C, 752B and 690C) (see Keller 1993), being restricted to low latitudes.

The most common and persistent species of the topmost Maastrichtian succession of the Bidart section is *Pseudoguembelina hariaensis*. This species co-occurs with *Pl. hantkeninoides* in low and middle latitudes K-
**Text-fig. 3.** Bidart section: lithology (A) and the detail of the K-Pg transition (B).
Pb boundary sections, and consequently may be used as a reliable biomarker for the latest Maastrichtian. Accordingly, a *Ps. hariaensis* Subzone, characterising the topmost part of the *Ab. mayaroensis* Zone, is proposed herein.

The *Ps. hariaensis* Subzone is dominated by small-sized species of the genus *Heterohelix* (*H. globulosa*, *H. labellosa*, *H. navarroensis* and *H. planata*), accompanied by species of the genera *Guembelitria*, *Globotruncanella*, *Hedbergella* and *Schackoina* which are smaller than 100 µm (Text-fig. 5; Gallala et al. 2009). The proportion of the larger-sized forms of the genera *Pseudotextularia*, *Racemiguembelina*, *Globotruncania*, *Globotruncanita* and *Contusotruncanita* (Text-fig. 5) does not exceed 2% in particular samples.

The *Guembelitria cretacea* Partial Range Zone: This zone, as defined originally by Smit (1982) and emended subsequently by Keller (1988), comprises the part of the range of its index taxon between the last occurrence of Cretaceous taxa (*Abathomphalus, Globotruncania, Gansserina, Pseudoguembelina*, among others) at the K/Pg boundary as delineated by the iridium spike, and the first appearance of *Parvularugoglobigerina eugubina*. The zone spans not more than 13 cm; the first occurrence of *Pv. eugubina* is noted in the < 100 µm fraction in samples B13–17 from the interval 13–17 cm above the K/Pg boundary. The fauna is very poor throughout the zone. The planktic foraminifers are rare and dominated by guembelitriids (*Guembelitria cretacea, Gt. trifolia*). Other small sized

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### Table: Systems, Stages and Index-species

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<th>Index-species</th>
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<td><em>P. eugubina</em></td>
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Text-fig. 4. Correlation between the proposed Uppermost Maastrichtian and Lowermost Danian planktic foraminiferal biozonations.
heterohelicids (H. globulosa, H. planata, H. navarroensis) are associated with tiny hedbergellids (Hedbergella holmdeensis, Hilla. monmoutethensis). Scarce larger-sized heterohelicids (Pseudoguembelina palpebra, Psg. kempensis, Psg. costulata) and globotruncanids (Globotruncanina insignis, G. rosetta, Globotruncanella pschadae) are present but most of them are broken and/or ferruginous. The guembelitriids and the small sized heterohelicids and hedbergellids are considered to be Cretaceous survivors. All the other specimens (larger-sized heterohelicids and globotruncanids) are potentially reworked.

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<td>SUBZONES</td>
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<td>Pseudoguembelina hariaensis</td>
<td>Eogloboferina trivialis</td>
<td>Subbotina triloculinae</td>
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<td>Palg. luterbachi</td>
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**Text-fig. 5.** Planktic foraminiferal ranges at the Bidart section
Its magnetostratigraphic position is in Chron C29r and its duration is either between 65.000 and 64.981 Ma (Berggren et al. 1995, Olsson et al. 1999: A) or between 65.500 and 65.478 Ma (Röhl et al. 2001: B).

Based on Parvularugoglobigerina longiapertura and Pv. eugubina being independent species (following Arenillas et al. 2000, 2004; see also Blow (1979), Arenillas and Arz 2000) the Gt. cretacea Zone is subdivided herein into two subzones: (1) The Hedbergella holmde-lensis Subzone, with its lower boundary defined by the base of the Gt. cretacea Zone and its top by the first appearance of Parvularugoglobigerina longiapertura; and (2) the Parvularugoglobigerina longiapertura Subzone, an interval zone, between the FAD of Pv. longiapertura and the FAD of Parvularugoglobigerina eugubina (Text-fig. 5). The successive occurrence of Pv. longiapertura and Pv. eugubina was also noted in El Kef, the K-Pg boundary stratotype section, as well as in the El-lès (Tunisia), Ain Settara (Tunisia), and the Caravaca and Agost sections in Spain (Molina et al. 1996, Arenillas et al. 2004).

The Gt. cretacea Zone as defined herein differs from the P0 biozone of Berggren and Miller (1988), Keller (1988), Berggren et al. (1995) and Olsson et al. (1999). These authors considered Pv. eugubina and Pv. longiapertura to be synonymous. On the contrary, it is close to the Globocoma conusa Zone of Zaghibb-Turki et al. (2000). At the Ellès section, these authors observed the first occurrence of Parvularugoglobigerina specimens (smaller than 100 µm) at 22 cm above the K-Pg boundary. A recent taxonomic review of these specimens (this work) allows them to be attributed to Pv. longiapertura.

The Parvularugoglobigerina eugubina Total Range Zone: This zone was defined originally by Luterbacher and Premoli Silva (1964), based on the Gubbio section in Italy. It must be stressed, however, that Luterbacher and Premoli Silva (1964) placed the FAD of Parvularugoglobigerina eugubina immediately at the K-Pg boundary and regarded this zone as lowermost Danian. Subsequently, it appeared, however, that the K-Pg boundary succession in Gubbio is not complete, with the Guembelitria cretacea Zone (and its equivalent P0 Zone of Blow 1979, Smit 1982, Berggren and Miller 1989, and Berggren and Norris 1997) missing. Moreover, Pv. eugubina as commonly used then (e.g. Bolli 1966; Stainforth et al. 1975; Toumarkine and Luterbacher 1985; Keller 1988; Berggren et al. 1995; Keller and MacLeod 1995) was used in a wider sense than used herein, i.e., including Pv. longiapertura, which has the effect of markedly lowering the base of the zone. Consequently, the base of this zone, as accepted herein, is defined by the FAD of Pv. eugubina senso stricto. It means that the base of our Pv. eugubina Zone is not exactly equivalent to that of e.g. Keller (1988), Keller and MacLeod (1995) or Berggren et al. (1995).

The upper boundary of the Pv. eugubina Zone is defined herein by the LAD of the eponymous taxon, in accordance with Premoli Silva and Luterbacher (1964), Toumarkine and Luterbacher (1985) and Berggren et al. (1995). This definition contrasts with that of other authors who define its top by the FAD of Ps. pseudobulloides. Actually, it is commonly accepted that both levels are very close to each other, with no or only a very slight overlap in the ranges of Pv. eugubina and Ps.
pseudobulloides (see Blow 1979; Liu 1993; Berggren et al. 1995). Both events, i.e., the LAD of *Pv. eugubina* and the FAD of *Ps. pseudobulloides* are also very close in the Bidart succession. We favour the LAD of *Pv. Eububina* as defining the upper boundary of the *Pv. eugubina Zone* because this bioevent is assumed to be more isochronous and this species is easier to identify. Additionally, this event coincides with other bioevents, such as the LAD of numerous species of the genera *Parvularugoglobigerina* and *Palaeoglobigerina* (e.g. *Pv. cf. hemisphaerica, Palg. alticonusa, Palg. fodina, Palg. luterbacheri, Pv. sabina, Palg. minutula*). This coincidence was also observed in the Caravaca section (Arenillas et al. 2004), and may well mark a biostratigraphically important event.

The *Pv. eugubina Zone* as defined herein differs slightly from the *G. eugubina Zone* of Smit (1982), Smit and Romein (1985), and Tomarkine and Luterbacher (1985). In its base it is different from the Pa zone of Berggren et al. (1995) and Olsson et al. (1999). However, it is close to the *Pv. eugubina Zone* of Zaghbib-Turki et al. (2000) in the first occurrence and the last occurrence of his index taxon *Parvularugoglobigerina eugubina*. It differs slightly in its top from the *Pv. eugubina Zone* of Arenillas et al. (2004) in view of the overlap in the ranges of *Ps. eugubina* and *Ps. pseudobulloides* noted in several sections.

Text-fig. 7. Correlation between Bidart (France) section and several other complete Cretaceous-Paleogene transition interval sections in middle (Zumaya: Spain) and low latitude (El Kef and Ellès: Tunisia; Caravaca: Spain)
It corresponds to the upper part of Chron C29r. Its estimated age is either between 64.981 and 64.945 Ma (A) or between 65.478 and 65.436 Ma (B). In the Bidart section, the Pv. *eugubina* Zone is 107 cm thick.

The zone is subdivided herein into the *Parvularugoglobigerina sabina* and the *Eoglobigerina simplicissima* subzones. The *Pv. sabina* Subzone, as previously defined (Arenillas et al. 2004), is an interval zone, between the FAD of *Pv. eugubina* and the FAD of *E. simplicissima*. The *E. simplicissima* Subzone, as defined herein, is the interval between the FAD of the eponymous species and the LAD of *Pv. eugubina*. In the Bidart section, these subzones are 40 cm and 67 cm thick respectively. Of importance is the observed LAD of *Pv. longiapertura* here in the lowermost part of the *E. simplicissima* Subzone, confirming the succession of taxa observed in the Zumaya section (Arenillas et al. 1998).

The *Parasubbotina pseudobulloides* Partial Range Zone: It is the renamed version (by Bolli 1966) of the *Globigerina pseudobulloides*- *G. daubjergensis* Zone of Leonov and Alimarina (1961). It is the interval between the LAD of *Pv. eugubina* and the FAD of *Globanomalina compressa*. Only the lower part of this zone is studied herein (Text-fig. 5).

Following Arenillas et al. (2004), we subdivide the *P. pseudobulloides* Zone into the *Eoglobigerina trivialis* and *Subbotina triloculinoides* subzones. The former corresponds to the interval between the LAD of *Pv. eugubina* and the FAD of *S. triloculinoides*, whereas the latter spans the interval between the FAD of *S. triloculinoides* and the FAD of *Gl. compressa*. At Bidart, the FAD of *S. triloculinoides* is observed at 93 cm above the LAD of *Pv. eugubina*. Throughout this zone, species of *Chilougembelina* and *Woodringina* dominate the planktic foraminiferal assemblages. These heterohelicids are associated with diverse species of *Eoglobigerina, Parasubbotina, Globanomalina* and *Praemurica*, which are less abundant. The base of the *Ps. pseudobulloides* Zone is marked by the appearance of a number of species (see Text-fig. 5). Most of these species seem to appear diachronously and, according to Arenillas et al. (2000 and 2004), only *Eoglobigerina trivialis* was shown to co-appear with *Ps. pseudobulloides* in the Caravaca and Ain Settara sections. In summary, these simultaneous appearances (Globanomalina compressa, Parasubbotina pseudobulloides, *Ps. varianta*, *Eoglobigerina edita*, *E. microcellulosa*, *E. trivialis*, *Pv. pseudoinconstans*, *Pv. inconstans*, *Globococonusa daubjergensis*) and extinctions (the genera *Palaeoglobigerina* and *Parvularugoglobigerina*) observed in the Bidart section from the base of the *Ps. pseudobulloides* Zone reflect a major turnover (see Gallala et al. 2009). Later in the Danian (across the *S. triloculinoides* Subzone) the assemblages became richer in species of *Subbotina* and *Praemurica* (see Acme-stage in Gallala et al. 2009).

**CONCLUSIONS**

- Based on high resolution biostratigraphic analysis, the Cretaceous-Paleogene boundary interval of the Bidart section in southern France may directly be compared with the El Kef boundary stratotype section and with the other auxiliary sections, located in the Atlantic and the Tethyan realms.
- All of the biozones and subzones are directly recognizable by their marker taxa. Similarly as in Zumaya (Spain), the uppermost Maastrichtian is documented by *Pv. eugubina*, a species with a wide geographic range, which we consider a good indicator of the topmost Cretaceous. The *G. cretacea* Zone in the Bidart section is less expanded than at El Kef and Ellès, but nearly equal to the equivalent zone in the Ain Settara section in Tunisia, and the Zumaya and Caravaca sections in Spain (Arenillas et al. 2000 and 2004). Despite its reduced thickness, it is relatively complete, as suggested by the FAD of *Pv. longiapertura* in its upper part, similarly as in the El Kef K/Pg boundary stratotype section and other auxiliary sections.
- The *Pv. eugubina* Zone is 107 cm thick. Although it is thinner than in El Kef (5.7 m as revised in this work) and Ellès (5.8 m according to Zaghib-Turki et al. 2000), it is thicker than in the Zumaya or Caravaca sections (63 cm and 68 cm respectively). This zone is subdivided into *Pv. sabina* and *E. simplicissima* subzones.
- The *E. trivialis* Subzone of the *Ps. pseudobulloides* Zone is less expanded than in the Zumaya, Caravaca, El Kef or Ellès sections (Text-fig. 7). Only the lower part of the *S. triloculinoides* Subzone was studied herein, still below the FAD of *Gl. compressa*.
- In summary, the Bidart section possesses a complete uppermost Maastrichtian–earliest Paleogene record, as documented by planktic foraminifers. Although this section is much less expanded than the El Kef or Ellès sections, it may be a very useful auxiliary section of the boundary interval for the middle latitudes.
- In the Bidart section, the K/Pg mass extinctions affected at least 53 species (globotruncanids and large heterohelicids) out of 72 species in total. Only a single species, *Archaeoglobigerina cretacea*, disappeared in the latest Maastrichtian, definitely below the K/Pg boundary. These sudden extinctions are noted within the rusty layer at the base of the K/Pg boundary dark clays, which are characterized by all the geochemical anomalies (Ir-anomaly, spinel, etc.).
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