Acta Geologica Polonica, Vol. 60 (2010), No. 2, pp. 243–255

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

NJOUD GALLALA[1] AND DALILA ZAGHBIB-TURKI[2]

Université de Tunis El Manar, Faculté des Sciences de Tunis, Département de Géologie, Unité de recherche GEODPS (UR: 02/UR/10-02), Campus universitaire, 2092 Tunis, Tunisia.
E-mails: [1] gnoujoud@gmail.com, [2]dalila.zaghbib@fst.rnu.tn

ABSTRACT:

Gallala, N. and Zaghbib-Turki, D. 2010. High resolution biostratigraphy based on planktic foraminifera across the Cretaceous–Paleogene transition at the Bidart section (SW France). *Acta Geologica Polonica*, **60** (2), 243–255. Warszawa.

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 documented 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.

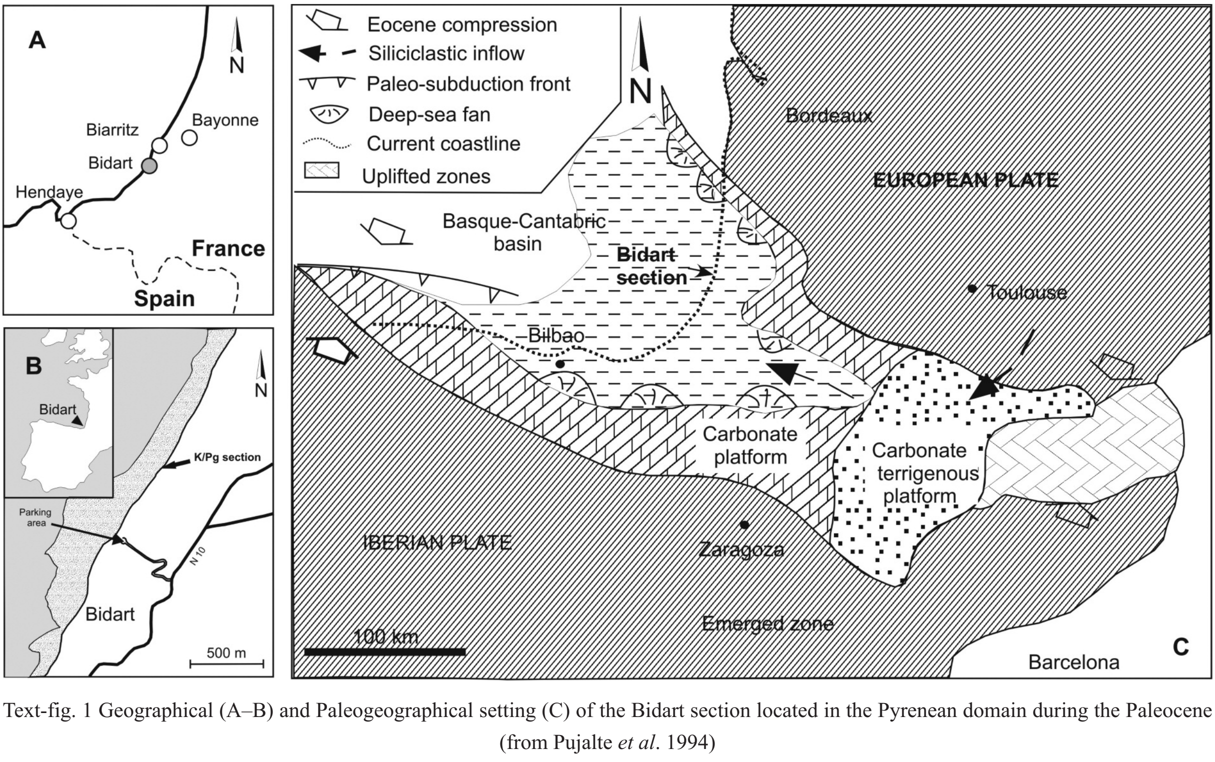
The planktic foraminiferal zonations and biochronology of the Upper Maastrichtian–Lower Danian of the middle and lower latitudes is still hotly debated (Text-fig. 5) (Smit 1982; Toumarkine and Luterbacher 1985; Keller 1988; Berggren *et al*. 1995; Olsson *et al*. 1999; Molina *et al*. 1996; Arenillas *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 Luterbacher 1985; Keller 1988; Stott and Kennett 1990; Canudo *et al*. 1991; Berggren *et al*. 1995; Molina *et al*. 1996; Arenillas *et al*. 1996, 1998, 2004; Arz *et al*. 2000; Zaghbib-Turki *et al*. 2000). The well exposed Cretaceous–Paleogene succession of Bidart has attracted the interest of many authors for decades, since when several multidisciplinary studies on stratigraphy, palaeogeographical setting, geochemistry and fossil content have been published (Renard *et al*. 1982; Delacotte *et al*. 1985; Ward 1988; Seyve 1990; Ward and Kennedy 1993; Hastel 1994; Gorostidi and Lamolda 1995; Apellaniz *et al*. 1997; Gardin *et al*. 1998; Galbrun *et al*. 2004; Minoletti *et al*. 2004).

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.

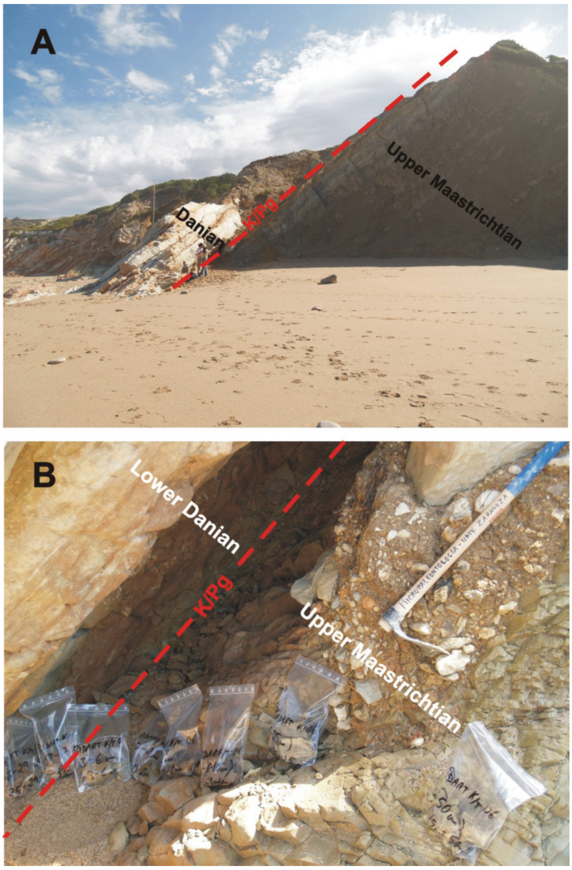
The uppermost Maastrichtian in the Bidart section (Text-fig. 3A), consist of alternations of metre-thick marls and argillaceous limestones with abundant foraminifers and scarce echinoids. The uppermost 2 cm



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 light 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.



Text-fig. 2. Photographs of the Bidart section. A – Overview of the Bidart K/Pg site where the samples are collected. B – Detail of the K/Pg boundary

The samples from the soft clayey or marly deposits were disaggregated in water with H_2O_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.

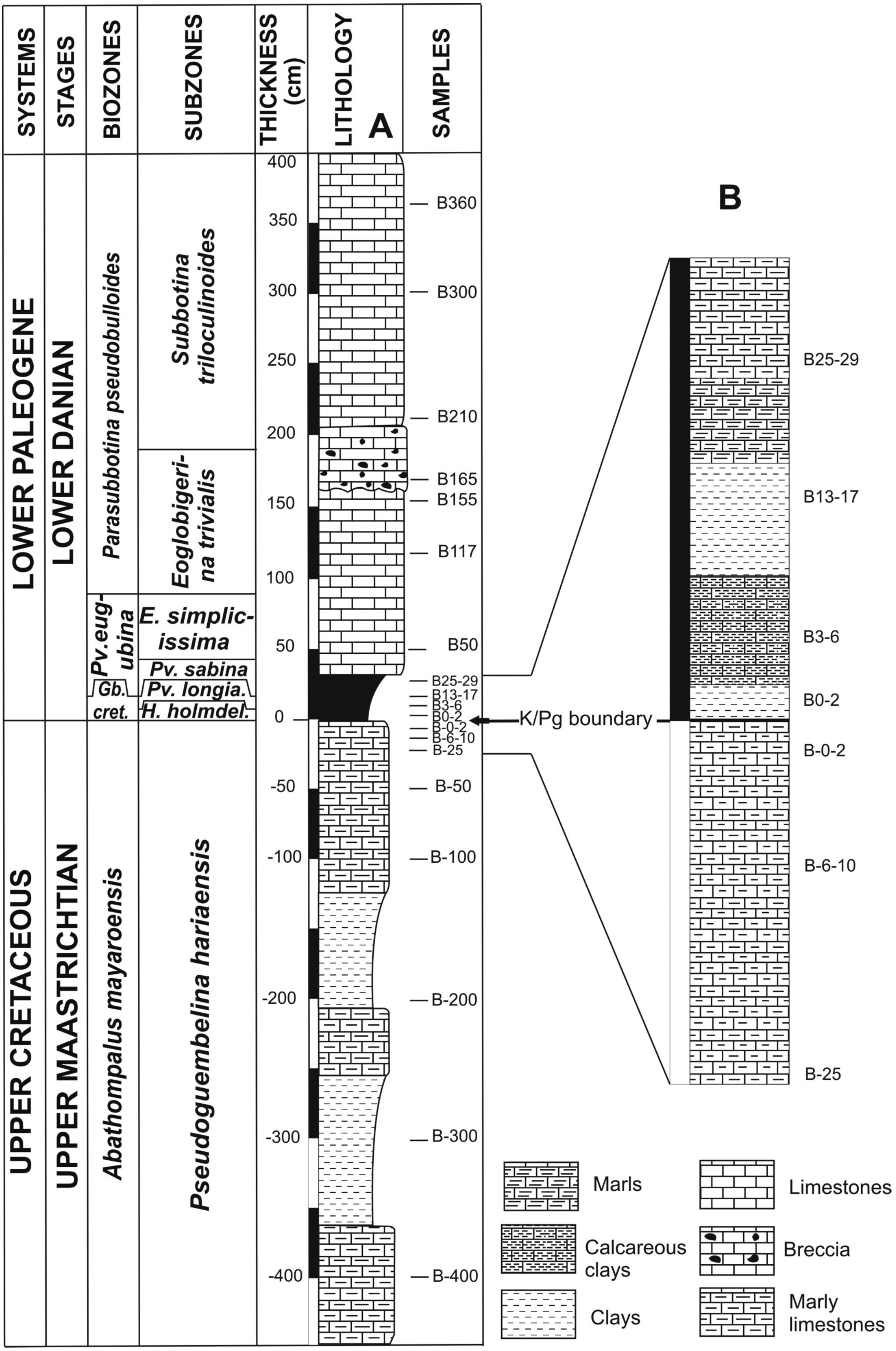
BIOSTRATIGRAPHY

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

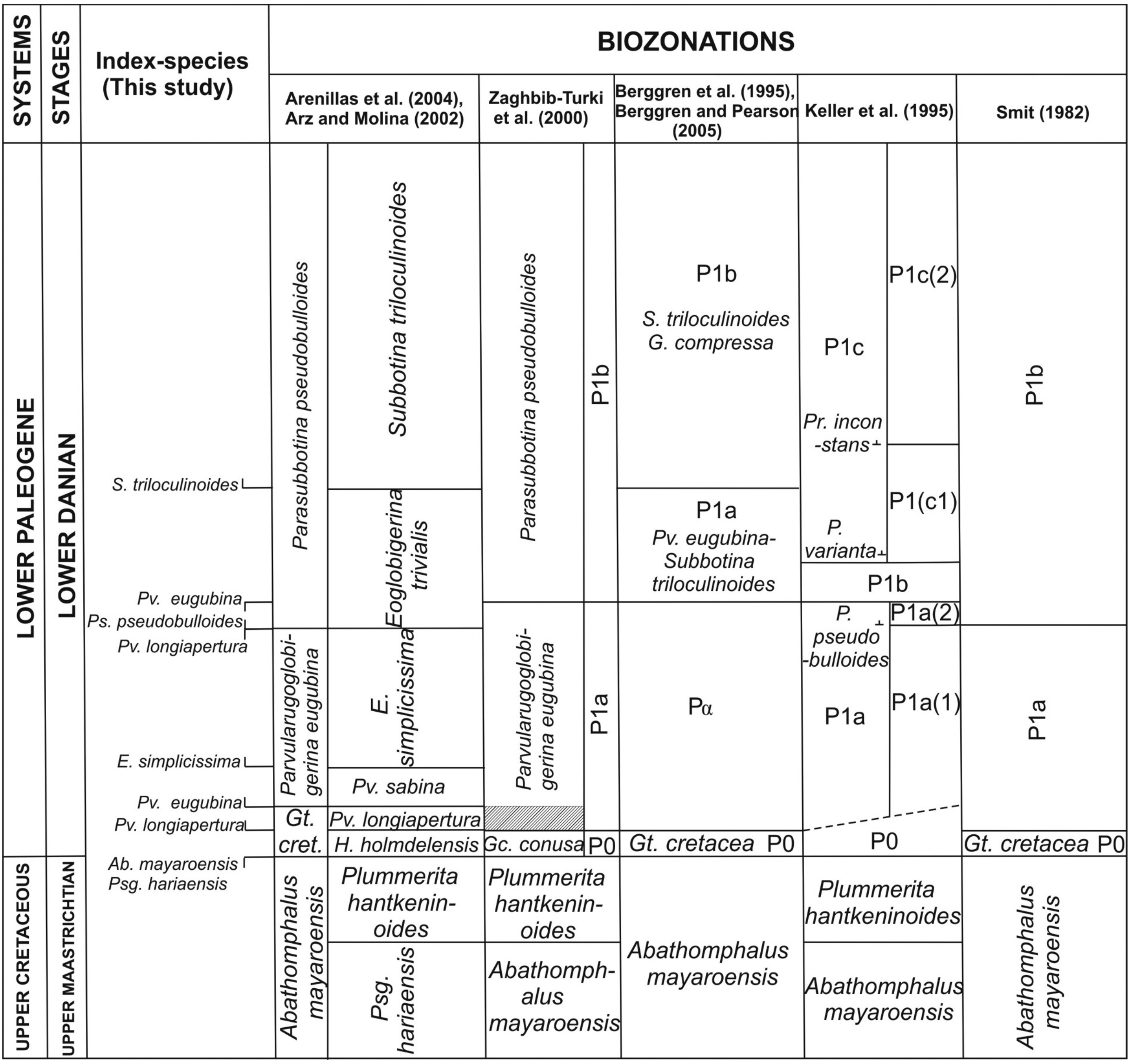
The *Abathomphalus mayaroensis* Total Range Zone: The zone is defined by the range of the nominative taxon (Bolli 1966) (Text-fig. 5) and has been widely recognized in the Tethyan area and elsewhere (Pessagno 1969; Postuma 1971; Premoli Silva and Bolli 1973; Sigal 1977; Robaszynski *et al.* 1983-1984; 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)

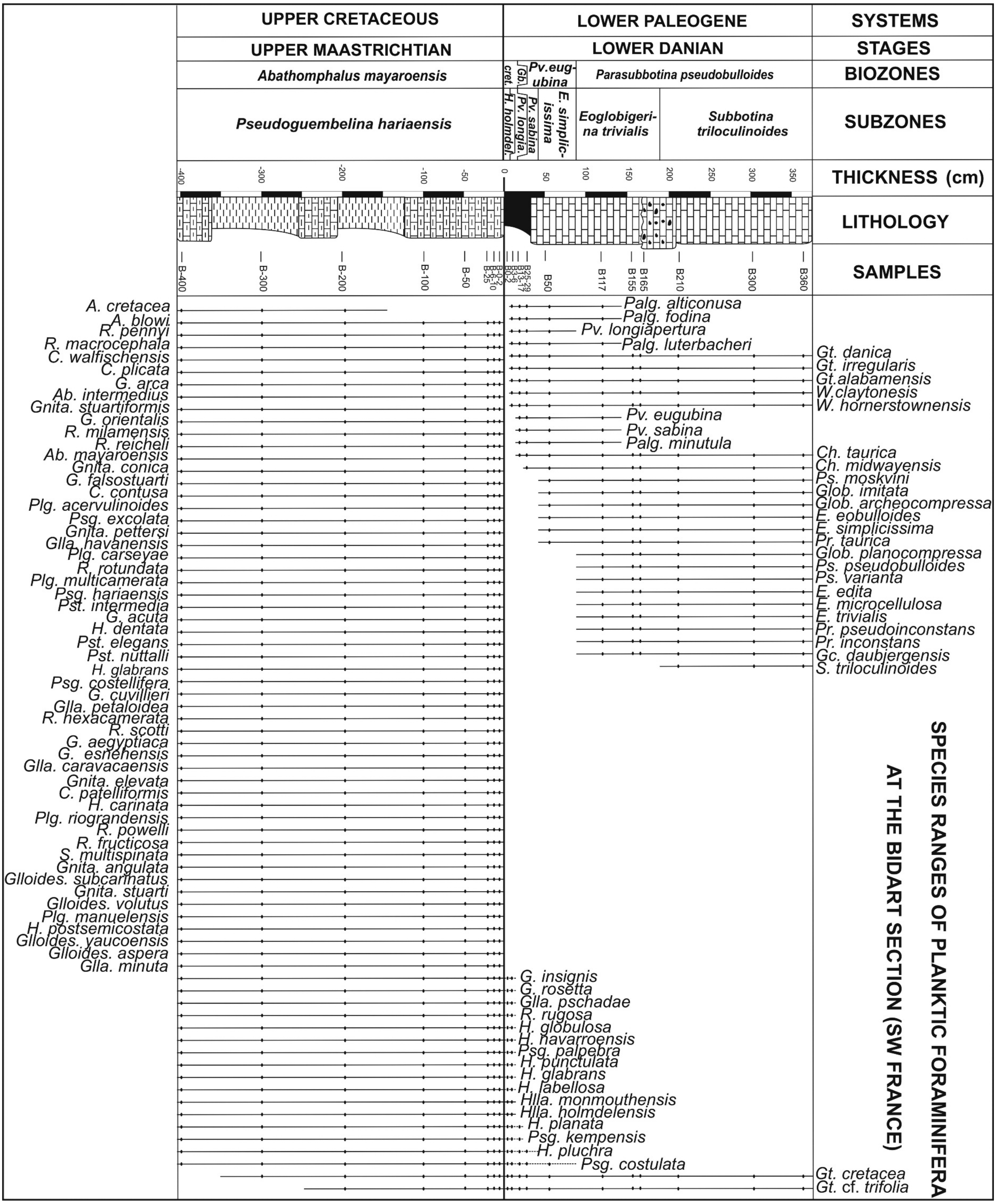


Text-fig. 4. Correlation between the proposed Uppermost Maastrichtian and Lowermost Danian planktic foraminiferal biozonations

Pg boundary sections, and consequently may be used as a reliable biomarker for the latest Maastrichtian. Accordingly, a *Psg. hariaensis* Subzone, characterising the topmost part of the *Ab. mayaroensis* Zone, is proposed herein.

The *Psg. 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, Globotruncana, Globotruncanita* and *Contusotruncana* (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, Globotruncana, 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 heterohelicids (*H. globulosa, H. planata, H. navarroensis*) are associated with tiny hedbergellids (*Hedbergella holmdelensis*, *Hlla. monmouthensis*). Scarce larger-sized heterohelicids (*Pseudoguembelina palpebra, Psg. kempensis, Psg. costulata*) and globotruncanids (*Globotruncana 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.



Text-fig. 5. Planktic foraminiferal ranges at the Bidart section

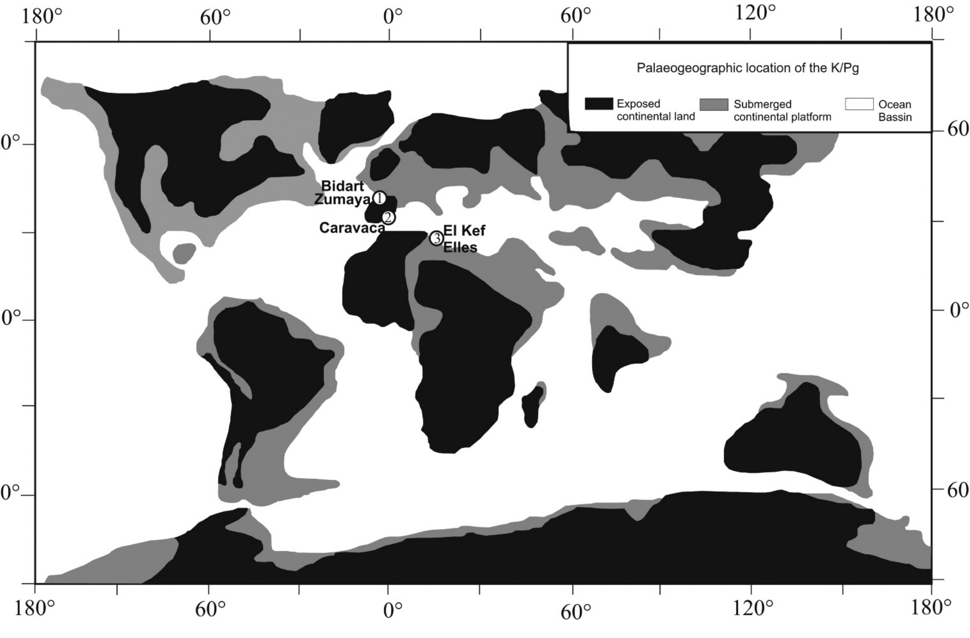
Its magnetostratigraphic position is in Chron C29r and its duration is either between 65.000 and 64.981 Ma (Berggren *et al*. 1995, Olsson *et al*. 1999: A) or between 65.500 and 65.478 Ma (Röhl *et al.* 2001: B).

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 holmdelensis* 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 Ellès (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 *Globoconusa conusa* Zone of Zaghbib-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*.

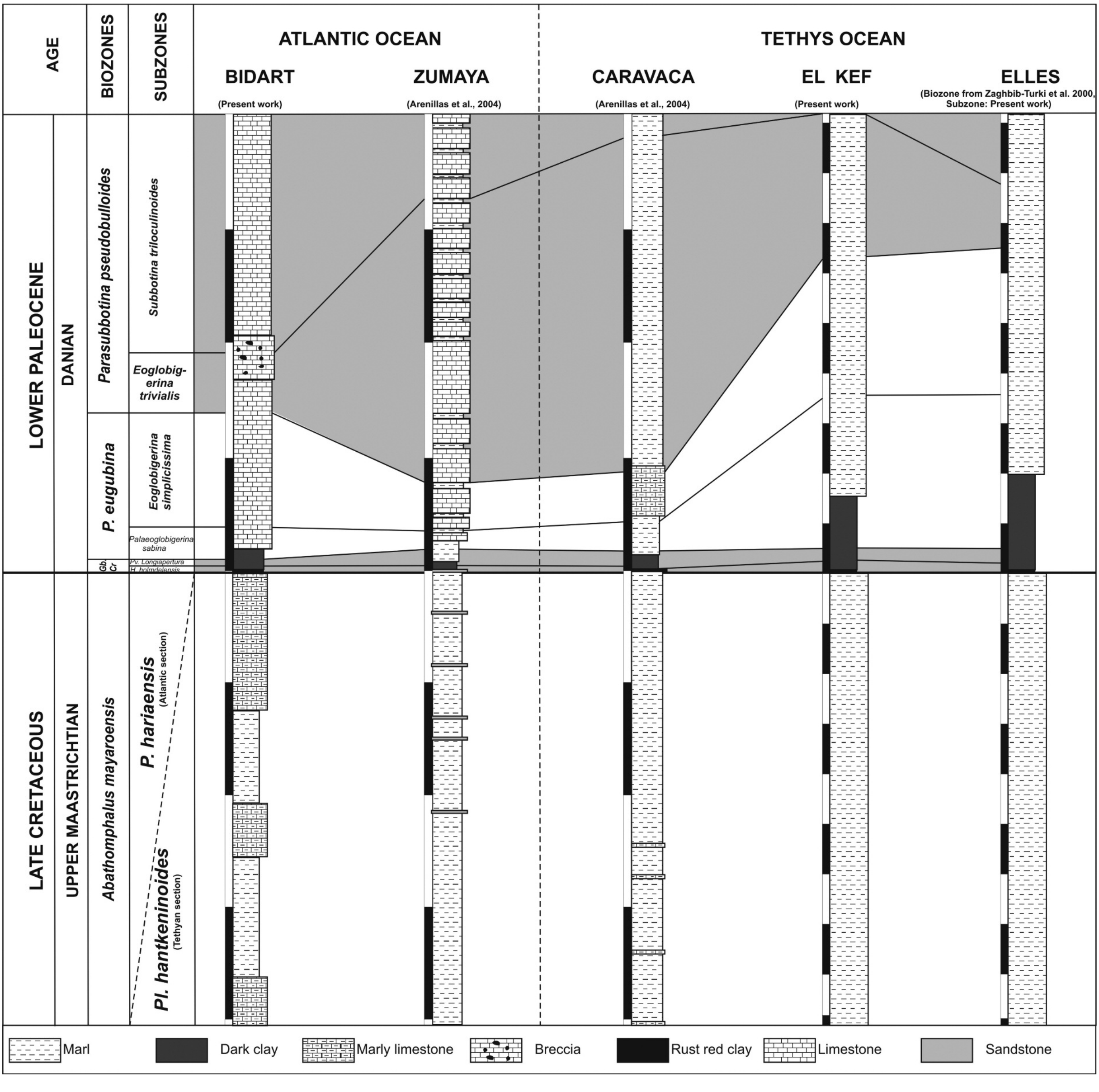
The *Parvularugoglobigerina eugubina* Total Range Zone: This zone was defined originally by Luterbacher and Premoli Silva (1964), based on the Gubbio section in Italy. It must be stressed, however, that Luterbacher and Premoli Silva (1964) placed the FAD of *Parvularugoglobigerina eugubina* immediately 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.*



Text-fig. 6. paleogeographic and Paleolatitudinal location of several sections showing a complete K-Pg transition *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. Eugubina* 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 Pα 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 *Pv. 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 *Chiloguembelina* 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, Pr. pseudoinconstans, Pr. inconstans, Globoconusa 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 recognisable by their marker taxa. Similarly as in Zumaya (Spain), the uppermost Maastrichtian is documented by *Psg. hariaensis*, a species with a wide geographic range, which we consider a good indicator of the topmost Cretaceous. The *Gt. 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 Zaghbib-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.).

Acknowledgments

This research was funded by the Spanish Ministerio de Educación y Ciencia and the Tunisian Ministry "Ministère de l'Enseignement Supérieur, de la Recherche Scientifique et de la Technologie" for the Tunisian-Spanish cooperation (AECI project A/4845/06, elaborated by Prof. Molina Eustoquio and Prof. Zaghbib-Turki Dalila). We thank Professor Molina Eustoquio, University of Zaragoza, Spain, for his help in the field and for the permission to work in his laboratory. We also thank Prof. Mohamed Moncef Turki, for his suggestions which improved this manuscript. We are grateful to Arenillas Ignacio and to Arz José Antonio, University of Zaragoza, for fruitful suggestions, and to Professor Michèle Caron, University of Freiburg, Switzerland, for constructive comments. The journal referees Dr. Danuta Peryt, Institute of Paleobiology of the Polish Academy of Sciences, and an anonymous reviewer, and also Richard Stephenson and Pr. Habib Ajroud, University of Manouba, Tunisia, are thanked for suggestions and improvements to the final version of our manuscript.

REFERENCES

Apellániz, E., Baceta, J.I., Bernaola-Bilbao, G., Núñez-Betelu, K., Orue-Etxebarría, X., Payros, A., Pujalte, V., Robin, E. and Rocchia, R. 1997. Analysis of uppermost Cretaceous–lowermost Tertiary hemipelagic successions in the Basque Country (western Pyrenees): evidence for a sudden extinction of more than half planktic foraminifer species at the K/T boundary. *Bulletin de la Societé Géologique de France*, **168**, 783–793.

Arenillas, I., Arz, J.A. and Molina, E. 1998. El límite Cretácico/Terciario de Zumaya, Osinaga y Músquiz (Pirineos): control bioestratigráfico y cuantitativo de hiatos con foraminíferos planctónicos. *Revista de la Sociedad Geológica de España*, **11**, 127–138.

Arenillas, I., Arz, J.A., Molina, E. and Dupuis, C. 2000. The Cretaceous/Tertiary boundary at Aïn Settara, Tunisia: sudden catastrophic mass extinction in planktic foraminifera. *Journal of Foraminiferal Research*, **30**, 202–218.

Arenillas, I., Arz, J.A. and Molina, E. 2004. A new high-resolution planktic foraminiferal zonation and subzonation for the lower Danian. *Lethaia*, **37**, 79–95.

Arz, J.A. and Arenillas, I. 1998. Foraminíferos planctónicos del tránsito Cretácico-Terciario del Pirineo occidental (España): Bioestratigrafía, análisis cuantitativo y Tafonomía. *Revista de la Sociedad Mexicana de Paleontología*, **(2)**, 146–162.

Arz, J.A., Arenillas, I., Molina, E. and Dupuis, C. 1999. Los efectos tafonómico y "Signor-Lipps" sobre la extinción en masa de foraminíferos planctónicos en el límite Cretácico/Terciario de Elles (Tunicia). *Revista de la Sociedad Geológica de España*, **12**, 251–267.

Arz, J.A., Arenillas, I., Molina, E. and Sepúlveda, R. 2000. La estabilidad faunística de los foraminíferos planctónicos en el Maastrichtiense superior y su extinción en masa catastrófica en el límite K/T de Caravaca, España. *Revista Geológica de Chile*, **27**, 27–47.

Arz, J.A. and Molina, E. 2002. Bioestratigrafía y cronoestratigrafía con foraminíferos planctónicos del Campaniense superior y Maastrichtiense de latitudes templadas y subtropicales (España, Francia, Tunicia). *Neues Jarbuch für Geologie und Paläontologie, Abhanlungen*, **224**, 161–195.

Berggren, W.A. 1971. Multiple Phylogenetic Zonations of the Cenozoic based on Planktonic Foraminifera. In: A. Farinacci, editor, Proceedings of the II Planktonic Conference, **1**, 41–56, Edizioni Tecnoscienza; Rome.

Berggren, W.A. and Miller, K.G. 1989. Cenozoic bathyal and abyssal calcareous benthic foraminiferal zonation. *Micropaleontology,* **35**, 308–320.

Berggren, W.A., Kent, D.V., Swisher III, C.C. and Aubry, M.P. 1995. A revised Paleogene Geochronology and Chronostratigraphy. In: Geochronology, Time and Global Stratigraphic Correlation (Eds W. A. Berggren *et al.*), Society of Economic Geologist and Paleontologist, Special Publication, 392 pp.

Berggren, W.A. and Norris, R.D. 1997. Biostratigraphy, phylogeny and systematics of Paleocene trochospiral planktic foraminifera. *Micropaleontology*, **43**, 1–116.

Berggren, W.A. and Pearson, P.N. 2005. A revised tropical to subtropical Paleogene planktonic foraminiferal zonation. *Journal of Foraminiferal Research*, **35**, 279–298.

Blow, W.H. 1979. The Cenozoic Globigerinida. Evert Jan Brill; Leiden, the Netherlands.

Bolli, H.M. 1966. Zonation of Cretaceous to Pliocene marine sediments based on Planktonic foraminifera. *Boletín informativo de la Asociación Venezolana de Geología Minera y Petrolera*, **9**, 1–34.

Bonté, P., Delacotte, O., Renard, M., Laj, C., Boclet, D., Jehanno, C. and Rocchia, R. 1984. An iridium rich layer at the Cretaceous/ Tertiary boundary in the Bidart section (southern France). *Geophysical Research Letter,* **11**, 473–476.

Canudo, J.I., Keller, G. and Molina, E. 1991. Cretaceous/Tertiary boundary extinction pattern and faunal turnover at Agost and Caravaca, S.E. Spain. *Marine Micropaleontology,* **17**, 319–341.

Caron, M. 1985. Cretaceous planktonic Foraminifera. *In*: Plankton stratigraphy Bolli Hans Martin, Saunders John Beckmann and Perch Neilson Katharina (Eds), pp. 17–86. Cambridge University Press.

Delacotte, O. 1982. Etude magnetostratigraphique et géochemique de la limite Crétacé–Tertiaire de la coupe de

Bidart (Pyrenees Atlantiques). Unpublished Ph.D. Dissertation, l'Université Pierre et Marie Curie, Paris 6, 162 pp.

Delacotte, O., Renard, M., Laj, C., Perch-Nielsen, K., Premoli Silva, I. and Clauser, S. 1985. Magnétostratigraphie et biostratigraphie du passage Crétacé–Tertiaire de la coupe de Bidart (Pyrenees Atlantiques). *Bulletin des Centres de Recherches Géologiques et Minières 1, Géologie de la France*, **3**, 243–254.

Denham, C.R. and Scotese, C.R. 1987. A Plate Tectonic Program for the Macintosh. Terra Mobilis, Geoimages, Austin, TX. 26 pp.

Galbrun, B. and Gardin, S. 2004. New chronostratigraphy of the Cretaceous–Paleogene boundary interval at Bidart (France). *Earth Planetary Science Letter,* **224**, 19–32.

Gallala, N., Zaghbib-Turki, D., Arenillas, I., Arz, J.A. and Molina, E. Planktic Foraminiferal catastrophic mass extinction and assemblage evolution across the Cretaceous/Paleogene (K/Pg) boundary at Bidart (SW France). *Marine Micropaleontology*, **72**, 196-209.

Gardin, S. and Monechi, S. 1998. Paleoecological change in middle to low-latitude calcareous nannoplankton at the Cretaceous/Tertiary boundary. *Bulletin de la Société Géologique de France,* **169**, 709–723.

Gardin, S. 2002. Late Maastrichtian to early Danian calcareous nannofossils at Ellès (Northwest Tunisia). A tale of one million years across the K–T boundary. *Palaeogeography Palaeoclimatology Palaeoecology* **178**, 211–231.

Gorostidi, A. and Lamolda, M.A. 1995. La nanoflora calcarea y el transito KT de la seccion de Bidart (SW de Francia). *Revista Española Paleontología,* N8 Homenaje al Dr. Guillermo, 153–168.

Haslett, S.K. 1994. Planktonic foraminiferal biostratigraphy and paleoceanography of the Cretaceous–Tertiary boundary section at Bidart, South-west France. *Cretaceous Research*, **15**, 179–192.

Huber, B.T. 1991. Paleocene and Early Neogene Planktonic Foraminifer Biostratigraphy of Sites 738 and744, Kerguelen Plateau (Southern Indian Ocean). In: J. Barron, B. Larsen, et al., *Proceedings of the Ocean Drilling Program, Scientific Results*, **119**, 427–449.

Karoui-Yaakoub, N., Zaghbib-Turki, D. and Keller, G. 2002. The Cretaceous-Tertiary (K-T) mass extinction in planktic foraminifera at Elles I and El Melah, Tunisia. *Palaeogeography, Palaeoclimatology, Palaeoecology,* **178**, 233–255.

Keller, G. 1988. Extinction, survivorship and evolution of planktic Foraminifera across the Cretaceous/Tertiary boundary at El Kef, Tunisia. *Marine Micropaleontology,* **13**, 239–263.

Keller, G. 1993. The Cretaceous-Tertiary boundary transition in the Antarctic Ocean and its global implications. *Marine Micropaleontology*, **21,** 1–45.

Keller, G., Li, L. and Macleod, N. 1995. The Cretaceous–Tertiary boundary stratotype section at El Kef, Tunisia: how catastrophic was the mass extinction? *Palaeogeography, Palaeoclimatology, Palaeoecology,* **119**, 221–254.

Leonov, V.P. and Alimarina, G.P. 1961. Stratigraphy and planktonic foraminifera of the Cretaceous-Paleogene "Transition" Beds of the central part of the North Caucasus. Collected Papers Geological Faculty, University of Moscow, to XXI International Geological Congress, 29–60.

Liu, C. 1993. Uppermost Cretaceous – Lower Paleocene Stratigraphy and Turnover of Planktonic Foraminifera across the Cretaceous/Paleogene Boundary. 181 p. Doctoral dissertation, Rutgers University.

Luterbacher, H.P. and Premoli-Silva, I. 1964. Biostratigrafia del limite Cretaceo–Terziario nell'Appennino centrale. *Revista Italiana di Paleontologia*, **70**, 67–117.

Minoletti, F., Rafelis, M., Renard and M., Gardin, S. 2004. Reworking of Maastrichtian-like calcareous nannofossils in the lowermost Danian sediments of Bidart section (France): isotopic evidence (carbon and oxygen). *Revue de micropaléontologie,* **47**, 145–152.

Molina, E., Arenillas, I. and Arz, J.A. 1996. The Cretaceous/Tertiary boundary mass extinction in planktic foraminifera at Agost, Spain. *Revue de Micropaléontologie*, **39**, 225–243.

Molina, E., Arenillas, I. and Arz, J.A. 1998. Mass extinction in planktic foraminifera at the Cretaceous/Tertiary boundary in subtropical and temperate latitudes. *Bulletin de la Societé Géologique de France*, **169**, 351–363.

Molina, E., Alegret, L., Arenillas, I., Arz, J.A., Gallala, N., Hardenbol, J., Luterbacher, H., Steurbaut, E., Vandenberghe, N. and Zaghbib-Turki, D. 2006. The Global Boundary Stratotype Section and Point for the base of the Danian Stage (Paleocene, Paleogene, "Tertiary", Cenozoic) at El Kef, Tunisia: original definition and revision. *Episodes,* **29** (4), 263–273.

Molina, E., Alegret, L., Arenillas, I., Arz, J.A., Gallala, N., Grajales-Nishimura, M., Murillo-Muneton, G. and Zaghbib-Turki, D. 2009. The Global Boundary Stratotype Section and Point for the base of the Danian Stage (Paleocene, Paleogene, "Tertiary", Cenozoic): auxiliary sections and correlation. *Episodes,* **32** (2), 84-95.

Olsson, R.K. and Liu, G. 1993. Controversies on the placement of the Cretaceous/Paleogene boundary and the K/P mass extinction of planktonic foraminifera. *Palaios*, **7**, 127–139.

Olsson, R.K., Hemleben, C., Berggren, W. A. and Chengjie, L. 1992. Wall texture classification of planktonic foraminifera genera in the lower Danian. *Journal of Foraminiferal Research*, **22**, 195–213.

Olsson, R.K., Hemleben, C., Berggren, W. A., Huber, B.T. Editors and members of the Paleogene planktonic foraminifera working group 1999. Atlas of Paleocene Planktonic Foraminifera. *Smithsonian Contributions to Paleobiology*, **85**, 1–252.

Peryt, D. 1980. Planktic foraminifera zonation of the Upper Cretaceous in the Middle Vistula River Valley, Poland. *Palaeontologia Polonica,* **41**, 3–101.

Pessagno, E.A. 1967. Upper Cretaceous planktonic Foraminifera from the Western Gulf Coastal Plain. *Paleontographica Americana,* **5** (37), 243–444.

Postuma, J.A. 1971. Manual of planktonic Foraminifera. Elsevier Publishing Company; Amsterdam. 420 pp.

Premoli Silva, I. and Bolli, H.M. 1973. Late Cretaceous to Eocene Planktonic Foraminifera and Stratigraphy of Leg 15 sites in the Caribbean Sea. In: N.T. Edgar, J.B. Saunders *et al*., Initial Reports of the Deep Sea Drilling Project, **15**, 499–547. U.S. Government Printing Office; Washington, D.C.

Rami, A., Zaghbib-Turki, D. and El Ouardi, H. 1997. Biostratigraphie (Foraminifères) et contrôle tectono-sédimentaire du Crétacé supérieur dans la région de Mejez El Bab (Tunisie septentrionale). *Géologie méditerranéenne*, **24** (1-2), 101–123.

Renard, M., Delacotte, O. and Letolle, R. 1982. Le strontium et les isotopes stables dans les carbonates totaux de quelques sites de l'atlantique et de la téthys. *Bulletin de la Société Géologique de France,* **24**, 519– 534.

Robaszynski, F. and Caron, M. 1979. Atlas de foraminifères planctoniques du Crétacé moyen (Mer Boréale et Téthys). *Cahiers de micropaléontologie,* Editions du centre national de la recherche scientifique, 181 pp.

Robaszynski, F., Caron, M., Gonzalez Donoso, J.M. and Wonders, A.A.H. 1983-1984. Atlas of Late Cretaceous globtruncanids. *Revista Micropaleontologia*, Paris, **26** (3-4), 305 p.

Robin, E. and Rocchia, R. 1998. Ni-rich spinel at the Cretaceous–Tertiary boundary of El Kef, Tunisia. *Bulletin de la Société Géologique de France,* **169**, 365–372.

Rocchia, R., Boclet, D., Bonté, P., Devineau, J., Jehanno, C. and Renard, M. 1987. Comparison des distributions de l'iridium observées à la limite Crétacé–Tertiaire dans divers sites Européens. *Mémoire de la Société Géologique de France,* **150**, 95–103.

Rohl, U., Ogg, J.G., Geib, T.L. and Wefer, G. 2001. Astronomical calibration of the Danian time scale. In: Kroon, D., Norris, R.D., and Klaus, A., eds., Western North Atlantic Palaeogene and Cretaceous Palaeoceanography. *Geological Society Special Publication*, **183**, 163–183.

Salaj, J. 1983. Microbiostratigraphie du Crétacé et du Paléogène de la Tunisie septentrionale et orientale (Hypostratotypes tunisiens). Congrès géologique international, 26ème session-1er centenaire, Paris, France. 238 p., 64 pl.

Schmitz, B., Keller, G. and Stenvall, O. 1992. Stable isotope and foraminiferal changes across the Cretaceous-Tertiary boundary at Stevns Klint, Denmark: Arguments for long-term oceanic instability before and after bolide and bolide impact. *Palaeogeography Palaeoclimatology Palaeecology,* **9**, 233–260.

Seyve, C. 1990. Nannofossil biostratigraphy of the Cretaceous–Tertiary boundary in the French Basque Country. *Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine*, **14**, 553–572.

Sigal, J. 1977. Essai de zonation du Crétacé méditerranéen à l'aide des foraminifères planctoniques. *Géologie Méditerranéenne,* **4** (2), 99–108.

Smit, J. 1977. Discovery of a planktonic foraminiferal association between the *Abathomphalus mayaroensis* Zone and the *"Globigerina" eugubina* Zone at the Cretaceous/Tertiary boundary in the Barranco del Gredero (Caravaca, SE Spain): A preliminary report. *I and II Koninklijke Nederlandse Akademie van Wetenschappen,* **80** (4), 280–301.

Smit, J. 1982. Extinction and evolution of planktonic foraminifera after a major impact at the Cretaceous/Tertiary boundary. In: Silver, L. T., and Schultz, P.H., (Eds), Geological Implications of Impacts of Large Asteroids and Comets on the Earth. *Geological Society of America Special Paper,* **190**, 329–352.

Smit, J. and Romein, A.J.T. 1985. A sequence of events across the Cretaceous-Tertiary boundary. *Earth and Planetary Science Letters,* **74**, 155–170.

Smit, J. and Ten Kate, W.G.H.Z. 1982. Trace-element patterns at the Cretaceous -Tertiary boundary: consequences of a large impact. *Cretaceous Research*, **3**, 307–332.

Stainforth, R.M., Lamb, J.L., Luterbacher, H., Beard, J.H. and Jeffords, R.M. 1975. Cenozoic planktonic foraminiferal zonation and characteristics of index forms. *The Uuniversity of Kansas Paleontological Contributions*, **62**, 1–425.

Stott, L.D. and Kennett, J.P. 1990. Antarctic Paleogene Planktonic Foraminifer Biostratigraphy: ODP Leg 113, Sites 689 and 690. In: P.F. Barker, J.P. Kennett *et al*., *Proceedings of the Ocean Drilling Program, Scientific Results*, **113**, 549–569.

Toumarkine, M. and Luterbacher, H.P. 1985. Palaeocene and Eocene planktonic Foraminifera. In: Bolli Hans Martin, Saunders John Beckmann and Perch Neilson Katharina (Ed.), Plankton Stratigraphy. Cambrige University Press, 87–154.

Ward, P.D. 1988. Maastrichtian ammonite and inoceramid ranges from Bay of Biscay Cretaceous–Tertiary boundary sections. In: Lamolda, M.A., Kauffman, E.G., Walliser, O.H. (Ed.), Palaeontology and evolution; extinction. *Revista Española Paleontología*, 119–126.

Ward, P.D. and Kennedy, W.J. 1993. Maastrichtian ammonites from the Biscay region (France Spain). *Journal of Paleontology*, **34** (67), 1–58.

Zaghbib-Turki, D., Karoui-Yaakoub, N., Belayouni, H., Rocchia, R. and Robin, E. 2000. Enregistrement des évènements remarquables de la limite Crétacé-Tertiaire dans la coupe d'Ellès (Tunisie). *Comptes rendus de l'Académie des sciences*, **331**, 141–149.

Zaghbib-Turki, D., Karoui-Yaakoub, N., Benzarti-Said, R., Rocchia, R. and Robin, E. 2001. Révision de la limite Crétacé-Tertiaire de la coupe d'Ellès (Tunisie centro-septentrionale). Proposition d'un nouveau stratotype. *Geobios*, **34**, 1, 25–37.

Zaghbib-Turki, D. and Karoui-Yaakoub, N. 2004. The Cretaceous-Tertiary (K-T) boundary in Ellès and the other Tunisian outcrops. 32nd International Geological Congress. (Florence-Italy, August 20–28), Field Trip Guide Book-P60.

Manuscript submitted: 8th January 2009
Revised version accepted: 15th April 2010