A new high-resolution planktic foraminiferal zonation and subzonation for the lower Danian

IGNACIO ARENILLAS, JOSÉ A. ARZ AND EUSTOQUIO MOLINA

LETHAIA

Arenillas, I., Arz, J.A. & Molina, E. 2004 03 15. A new high-resolution planktic foraminiferal zonation and subzonation for the lower Danian. *Lethaia*, Vol. 37, pp. 79–95. Oslo. ISSN 0024-1164

A new planktic foraminiferal zonation has been established for the lower Danian, based on some of most expanded and continuous pelagic sections known to date (from Spain, Tunisia and Mexico). This biozonation is considered valid for low and middle latitudes. The maximum stratigraphical distribution of the index-species approximately coincides in all the studied sections. The index-species are abundant and easily recognizable. We propose the following biozones and subzones: *Guembelitria cretacea* Zone and the *Hedbergella holmdelensis* and *Parvularugoglobigerina longiapertura* subzones; the *Parvularugoglobigerina eugubina* Zone, which is subdivided into the *Parvularugoglobigerina sabina* and *Eoglobigerina simplicissima* subzones and the *Parasubbotina pseudobulloides* Zone with the *Eoglobigerina trivialis* and *Subbotina triloculinoides* subzones. A biomagnetostratigraphic correlation and calibration of the stratigraphical ranges of these species suggest that the biohorizons used to define the new biozonation are very isochronous, at least in the geographical areas analysed. □ *Biomagnetochronology, biostratigraphy, Danian, foraminifera, Palaeogene.*

Ignacio Arenillas [ias@unizar.es], José Antonio Arz [josearz@unizar.es] & Eustoquio Molina [emolina@unizar.es], Departamento de Ciencias de la Tierra, Universidad de Zaragoza, E-50009 Zaragoza, Spain; *17th May 2002, revised 17th January 2004.*

After the Cretaceous-Palaeogene (K-Pg) mass extinction, small and new planktic foraminifer species began to appear following a model of 'explosive' adaptive radiation (Luterbacher & Premoli Silva 1964; Smit 1982; D'Hondt 1991; MacLeod 1993; Arenillas *et al.* 1998; Olsson *et al.* 1999). High-resolution zonations can be obtained in the lowermost part of the Danian due to the rapid evolution and diversification of lower Danian planktic foraminifers. Micropalaeontologists have tended to establish more detailed zonations for the Danian in order to describe the bio- and chronostratigraphy of the different and rapid evolutionary events after the K-Pg mass extinction. Ever since the definition of the *Globigerina eugubina* Zone by Luterbacher & Premoli Silva (1964) and the P0 or *Guembelitria cretacea* Zone by Smit (1982), the standard biozones of the new lowermost Danian zonations have been subdivided into different subzones (Smit & Romein 1985; Keller 1988, 1993).

None of the zonations defined for the lowermost Danian is completely free of taxonomic problems. Different planktic foraminifer taxonomies have been proposed in the past for the lower Danian, most notably Luterbacher & Premoli Silva (1964), Stainforth *et al.* (1975), Blow (1979), Toumarkine & Luterbacher (1985), D'Hondt (1991), Liu & Olsson (1992), Olsson *et al.* (1992) and Li *et al.* (1995). Recently, Berggren and Norris (1997) and Olsson *et al.* (1999) have completed a new and important revision of the planktic foraminifer taxonomy of the Paleocene. Moreover, they proposed possible phylogenetic relationships among the species, mainly based on DSDP sites and USA Gulf Coast sections.

The maximum stratigraphic distributions of the species presented in Olsson *et al.* (1999) differ from those given by Molina *et al.* (1996, 1998) and Arenillas (2000) in Tethyan sections. The biostratigraphic data from the latter studies suggests a different interpretation of the systematics and phylogenetics of foraminiferids in the lowermost Danian (Arenillas & Arz 1996, 2000).

The new lower Danian zonation and subzonation proposed here is mainly based on some of the most expanded pelagic sections worldwide. Planktic foraminiferal evolutionary events and biomagnetochronologic calibrations were used to further improve the lowermost Danian biostratigraphy with the definition of new subzones, valid for low and middle latitudes.

Reference sections

The zonation and subzonation proposed below are mainly based on pelagic sections from Spain (Car-

Taylor & Francis
Taylor & Francis Group

DOI 10.1080/00241160310005097

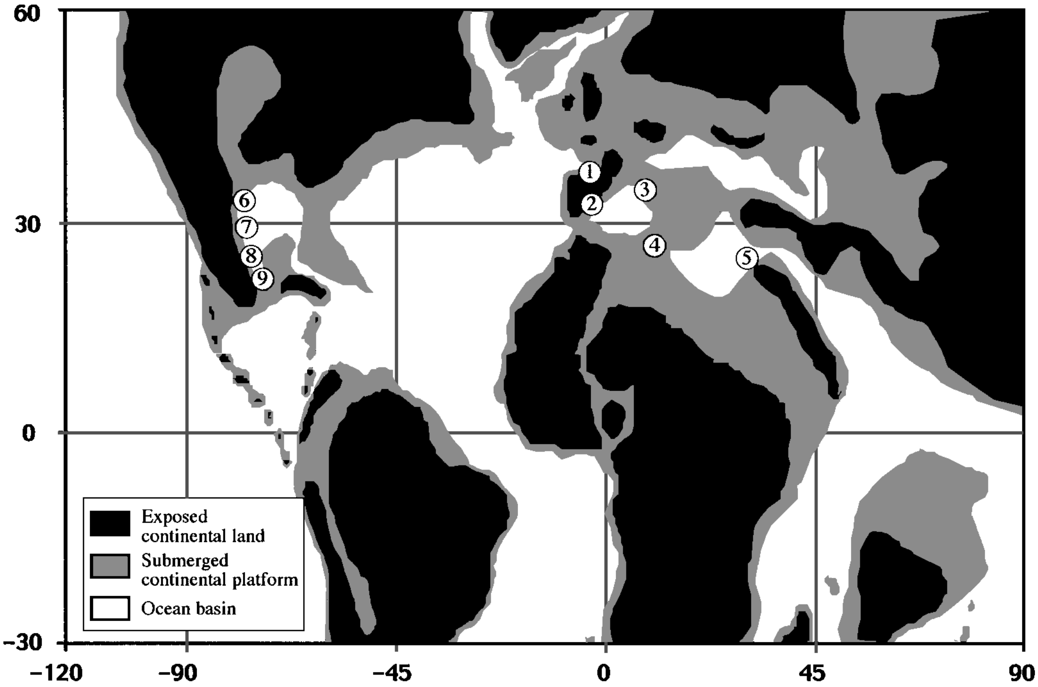

Fig. 1. Paleolatitudinal and paleogeographic location of the main sections studied. 1: Zumaya, Sopelana, San Sebastián and Bidart (Pyrenees, Spain-France); 2: Caravaca and Agost (Betic Cordillera, Spain); 3: Gubbio and Ceselli (Italy); 4: El Kef, Aïn Settara and Elles (Tunisia); 5: Ben Gurion (Israel); 6: El Mulato (northeastern Mexico); 7: El Mimbral and La Lajilla (northeastern Mexico); 8: Coxquihui and La Ceiba (central-eastern Mexico); 9: Bochil and Guayal (southeastern Mexico).

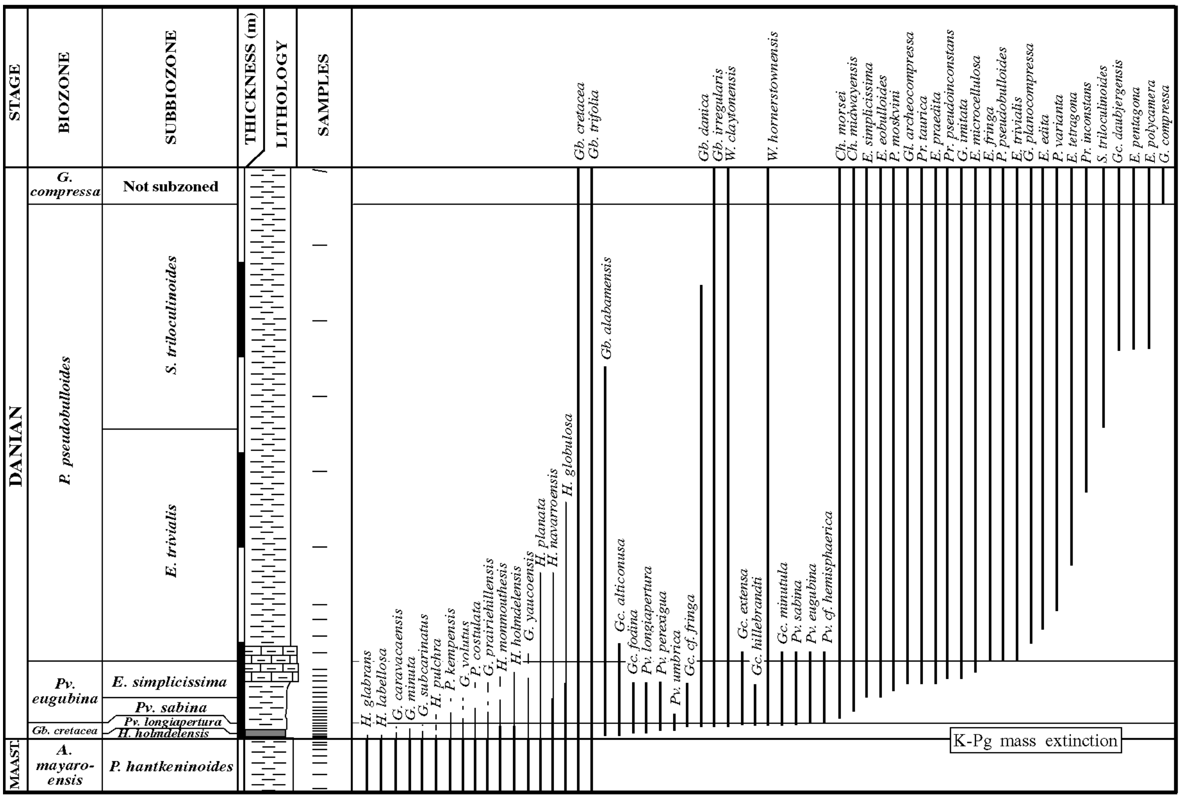

Fig. 2. Stratigraphical distribution of lower Danian planktic foraminifera at the Caravaca section (based on Arz *et al.* 2000). Thick line means probable species range and thin line probable reworked specimens.

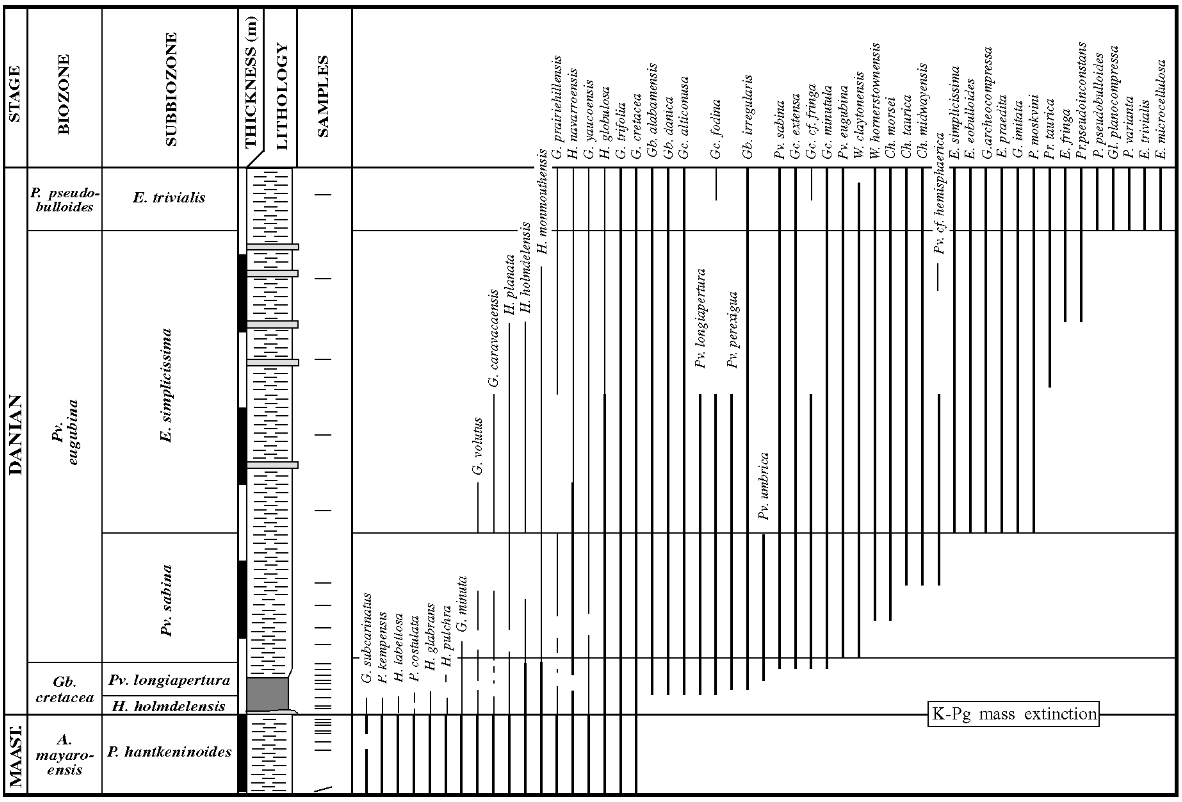

Fig. 3. Stratigraphical distribution of lower Danian planktic foraminifera at the Aïn Settara section (based on Arenillas *et al.* 2000b). Thick line means probable species range and thin line probable reworked specimens.

avaca, Agost, Zumaya), Tunisia (El Kef, Aïn Settara, Elles) and Mexico (La Lajilla, Coxquihui, El Mulato, Bochil) (Fig. 1). Other Tethyan, Atlantic and Gulf Coast K-Pg sections such as Gubbio and Ceselli (Italy), Ben Gurion (Israel), Bidart (France) and El Mimbral, La Ceiba and Guayal (Mexico) were used to verify its usefulness at low and middle latitudes (Fig. 1; Arenillas 2000; Arenillas & Arz 2000; Arz *et al.* 2001a). The sections were chosen to cover a broad geographic area in low and middle latitudes of the Northern Hemisphere. Due to their good continuity and exposure, Aïn Caravaca and Settara sections are the reference sections proposed for the definition of zones and subzones (Figs 2, 3).

Spain

The most expanded and continuous K-Pg sections known in Spain are Agost and Caravaca (Figs 2, 7), located in the Betic Cordillera (southeastern Spain), and Zumaya, in the western Pyrenees (northern Spain). The two Betic sections are similar, although Caravaca sedimentation rate in the lower Danian is around twice that of Agost. The K-Pg boundary in both sections is marked by a thin 10 cm black clay layer with a basal 2 mm thin rust-red layer containing an Ir anomaly and other impact evidence, such as altered microtektites (Smit 1982). At Zumaya, the boundary clay is also 10 cm thick, but the basal part has a 1–2 cm diagenetic calcitic layer. Similar sections to Zumaya were found in the Pyrenees in northern Spain and southern France (Rocchia *et al.* 1987; Apellaniz *et al.* 1997; Arz & Arenillas 1998). Some of them, such as Bidart, Sopelana and San Sebastián, contain a 1–2 mm thin rust-red layer with impact evidence in the basal part of the boundary clay.

Tunisia

The sections from Tunisia (Figs 3, 8), including the K-Pg stratotype section at El Kef, are much more expanded than the Spanish sections. The K-Pg boundary clay in the El Kef section is 50 to 60 cm thick. Nevertheless, the marly clay with low $CaCO_3$ content, equivalent to boundary clay in Spanish sections, is more than 150 cm thick. A 2–3 mm thin rust-red layer with impact evidence (Ir anomaly, Ni-spinels, altered microtektites, etc.) at the base of this

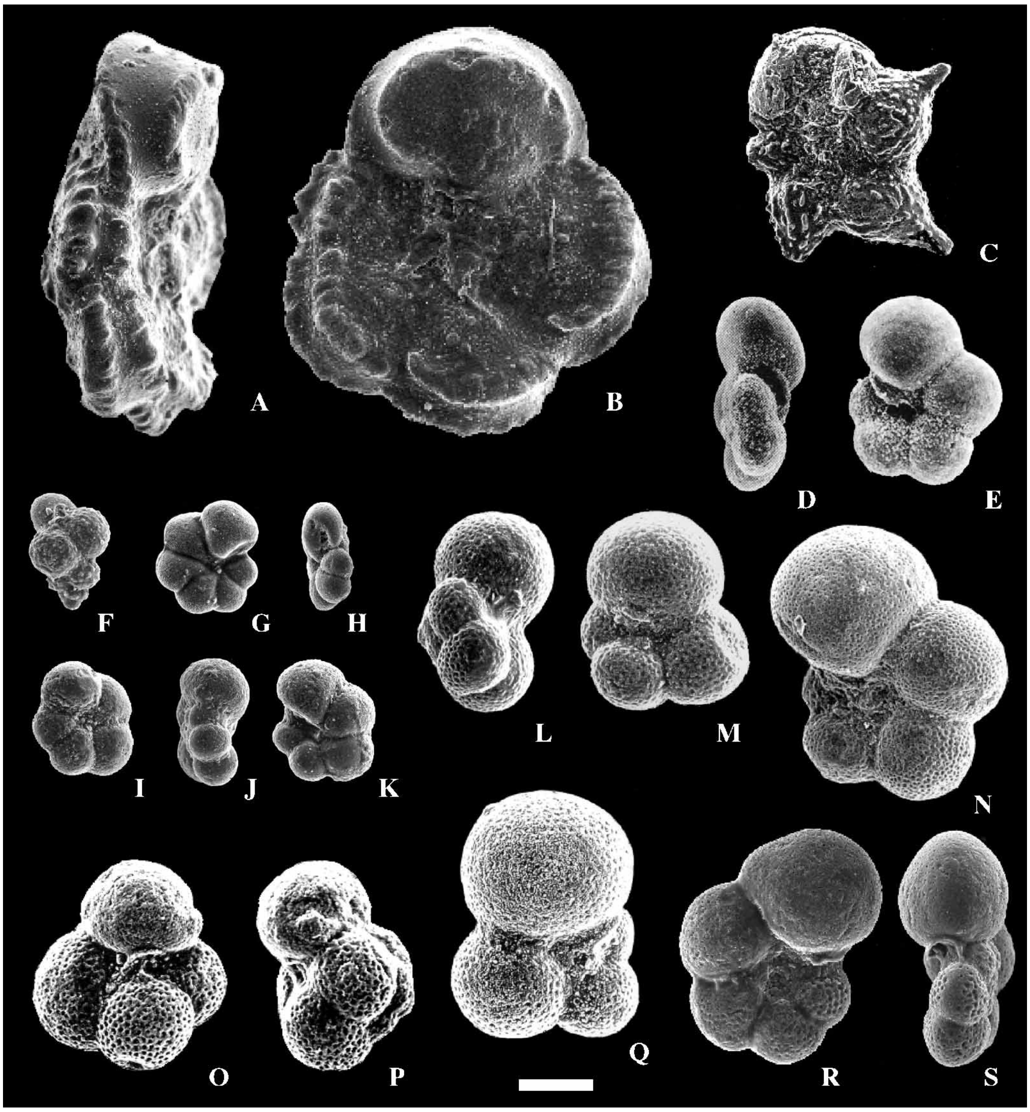

Fig. 4. SEM images of the planktic foraminiferal index-species (scale bar = 100 μm): □A–B. *Abathomphalus mayaroensis*, from Aïn Settara, Tunisia; □C. *Plummerita hantkeninoides*, from Caravaca, Spain; □D–E. *Hedbergella holmdelensis*, from DSDP Leg 32, Shatsky Rise, Northwestern Pacific (SEM image from Smith & Pessagno 1973); □F. *Guembelitria cretacea*, from Aïn Settara, Tunisia; □G–H: *Parvularugoglobigerina longiapertura*, from Aïn Settara, Tunisia; □I. *Parvularugoglobigerina sabina*, from Agost, Spain; □J–K. *Parvularugoglobigerina eugubina*, from Aïn Settara, Tunisia; □L–M. *Eoglobigerina simplicissima*, from Aïn Settara, Tunisia; □N. *Parasubbotina pseudobulloides*, from Aïn Settara, Tunisia; □O–P: *Eoglobigerina trivialis* from Caravaca, Spain; □Q. *Subbotina triloculinoides*, from Aïn Settara, Tunisia; □R–S: *Globanomalina compressa*, from Ben Gurion, Israel.

clay unit marks the boundary event (Robin & Rochia 1998). El Kef is the most continuous and expanded K-Pg pelagic section known to date. The Elles section, in central Tunisia, is also a very expanded section, since the boundary clay is 60 cm thick, with basal 3 cm thin yellow clay containing jarosite and iron oxide. As at El Kef, Elles had marly clay with low $CaCO_3$ content above the K-Pg boundary that spanned more than 150 cm (Arz *et al.* 1999).

Another interesting and very continuous section is Aïn Settara in central northwestern Tunisia (Fig. 3). A yellow to red horizon with jarosite is present at the basal part of the 55 cm thick dark boundary clay giving evidence of an impact event (Dupuis *et al.* 2001).

Mexico

The Mexican sections contain very thick clastic deposits ('K-Pg boundary cocktail' *sensu* Bralower *et al.* 1998, fig. 9), which are related with the K-Pg impact event. In north and central-eastern Mexico, the clastic units were deposited under a high sedimentation rate in upper flow regimes and accumulated as a single-pulse event at lower bathyal depths (Arz *et al.* 2001a;

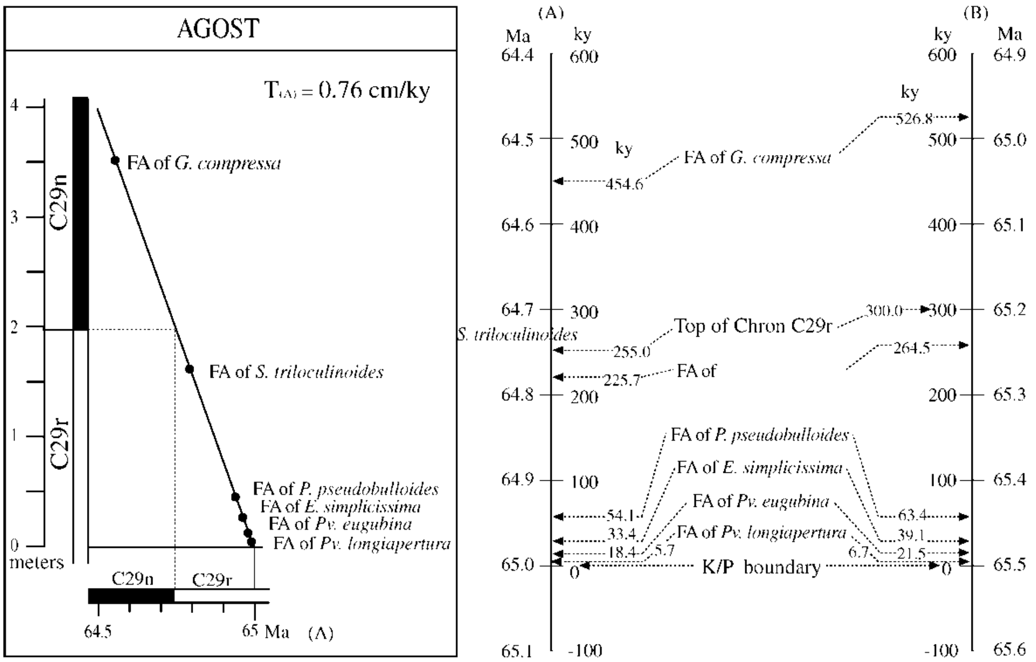

Fig. 5. Biomagnetostratigaphic correlation at the Agost section and calibration of the first appearances of the index-species (average age based on Agost, Caravaca and Zumaya sections). (A) = time-scale by Berggren *et al.* (1995); (B) = time-scale by Röhl *et al.* (2001); T(A) = average sedimentation rates between the K/Pg boundary and the top of C29r according to the time-scale by Berggren *et al.* (1995).

Soria *et al.* 2001; Alegret *et al.* 2001a). At Coxquihui, central-eastern Mexico, the clastic unit includes a 20-cm to 1-m thick spherule-bearing bed containing marly and calcareous boulders. The clastic unit at the El Mulato section in northeastern Mexico has an overall thickness of 2 m with a 10-cm thick tabular bed in its lower part containing abundant spherules (Alegret *et al.* 2002). In other Mexican sections such as El Mimbral similar spherules with a diameter of 2 to 5 mm have been reported as altered microtektites that originated from the K-Pg meteoritic impact (Smit *et al.* 1996) and resedimented by gravity flow (Soria *et al.* 2001). The stratigraphic sequence at La Lajilla is similar to El Mulato, but the clastic unit only spans 1 m. In southern Mexico, near the Chicxulub crater, the Bochil and Guayal sections have thick breccia with meter long blocks in the lower part of the clastic unit. They are interpreted as gravity flow deposits formed by seismic shacking triggered by the impact at Yucatan (Grajales *et al.* 2000). According to the K-Pg stratotype definition from El Kef (Tunisia), the K-Pg boundary at Mexican sections must be placed at the base of the clastic unit, which must be considered Danian in age (Smit *et al.* 1996; Arz *et al.* 2001a; Arenillas *et al.* 2002). The clastic unit contains very badly preserved Upper Cretaceous species. For this reason, we considered the clastic unit as an azoic interval but with reworked Cretaceous specimens.

Taxonomic notes

The taxonomy and systematic for the planktic foraminifers are based on Luterbacher & Premoli Silva (1964), Blow (1979), Arenillas & Arz (1996), Berggren & Norris (1997), Olsson *et al.* (1999) and Arenillas (2000). Scanning Electron Microscopy (SEM) images of the index species used for the definition of biozones and subzones are shown in Figure 4.

The Berggren and Norris (1997) and Olsson *et al.* (1999) taxonomy and that proposed by Arenillas (2000) are similar, but the latter author considered more morphospecies. This splitting taxonomy increases the biostratigraphical resolution because more biostratigraphic data can be used to define zones and subzones. There is one main difference between the two taxonomies: Arenillas (2000) differentiates *Parvularugoglobigerina longiapertura* and *Parvularugoglobigerina eugubina* by the aperture shape (Fig. 4) being high-arched in the former and low-arched in the latter (Canudo *et al.* 1991; Arenillas & Arz 2000). This taxonomic differentiation is very significant for the lowermost Danian biozonation since the first appearance of *Parvuglobigerina longiapertura* occurs before *Parvuglobigerina eugubina* and the lowest stratigraphic record of both morphospecies have been used to define biozones (for example, *Parvularugoglobigerina longiapertura* Biozone; Canudo

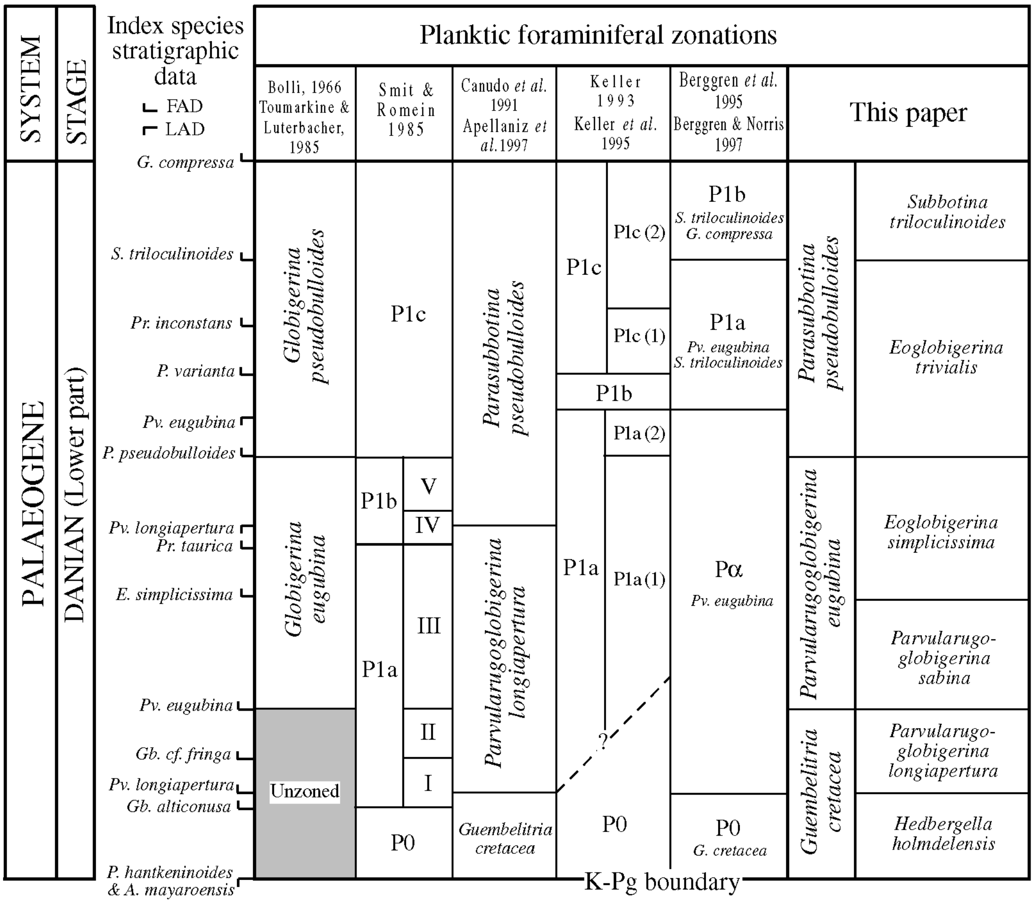

Fig. 6. Comparison of the biozonation proposed in this paper with the most relevant planktic foraminiferal zonations across the K-Pg boundary.

et al. 1991). Moreover, the first appearance of *Parvuglobigerina longiapertura* is very close to the first appearance of *Globoconusa*? *alticonusa* (= *Parvularugoglobigerina alabamensis* of Olsson *et al.* 1999). The lowest known stratigraphic record of both species is very similar in all the studied sections and the morphological differences between them (very high trochospiral, 4 chambers per whorl in *Globoconusa*? *alticonusa* and flatten trochospiral, 5–6 chambers per whorl in *Parvularugoglobigerina longiapertura*) are evident since the beginning. For these reasons, Arenillas & Arz (1996) proposed two different ancestors for *Globoconusa*? *alticonusa* and *Parvularugoglobigerina longiapertura*. The ancestral species of *Globoconusa*? *alticonusa* was surely *Guembelitria cretacea* and *Guembelitria*? *alabamensis* was an intermediate species (Arenillas 2000).

A controversial problem regarding the K-Pg boundary is to differentiate between reworked and indigenous Cretaceous specimens in the lowermost Danian strata i.e. to identify which Cretaceous planktic foraminifera survived. Isotopic studies have shown that *Heterohelix globulosa, Heterohelix navarroensis, Guembelitria cretacea, Guembelitria* cf. *trifolia, Hedbergella holmdelensis* and *Hedbergella monmouthensis* are probable survivors (Barrera & Keller 1990; Huber 1996). The size of all these species decreases in the lowermost Danian (Arenillas *et al.* 2000a, b) and pore-mounds and pustules of their walls tend to be modified and/or disappear (Arenillas 2000).

Berggren and Norris (1997) and Olsson *et al.* (1999) consider that *Guembelitria cretacea* and *Hedbergella* are the ancestral species of the different lowermost Danian genera. They suggested that *Hedbergella* is the immediate ancestor of *Globanomalina, Praemurica, Parasubbotina* and *Eoglobigerina*, but this idea is not supported by our biostratigraphy data. The known LAD (= last appearance datum) of *Hedbergella* is in the *Guembelitria cretacea* Zone and the FAD (= first appearance datum) of the first species of the genera mentioned above (i.e. *Eoglobigerina simplicissima, Globanomalina archeocompressa, Parasubbotina moskvini* and *Praemurica taurica*) is in the upper part of *Parvularugoglobigerina eugubina* Biozone. *Hedbergella* and these last species do not coincide in the stratigraphic record of the main sections and do not seem to have phylogenetic relations. Arenillas & Arz (1996) and Arenillas (2000) suggested *Hedbergella holmdelensis* as the possible ancestor of *Parvularugoglobigerina longiapertura*. We have chosen *Hedbergella holmdelensis* as nominate species for the first Danian subzone equivalent to Zone P0 in Smit (1982) and Berggren *et al.* (1995).

Calibration of the biostratigraphic data

The planktic foraminiferid biostratigraphy of respectively Agost (Molina *et al.* 1996), Zumaya (Arenillas *et al.* 1998), Elles (Arz *et al.* 1999), Caravaca (Arz *et al.* 2000), El Kef (Arenillas *et al.* 2000a), Aïn Settara (Arenillas *et al.* 2000b), Coxquihui (Arz *et al.* 2001b) and Bochil (Arenillas *et al.* 2002) served as the basis for the present study. A preliminary zonation from La Lajilla and El Mulato can be found in Alegret *et al.* (2001b, 2002). There were no significant hiatuses in any of the Spanish and Tunisian sections except for the Elles section. All the biozones and subzones could be identified, but a hiatus was recognized between the *Parvularugoglobigerina eugubina* and *Parasubbotina pseudobulloides* Zones at the Elles section (Arz *et al.* 1999). The biozones and subzones at the Mexican sections have an intermediate thickness between the Spanish and the Tunisian sections. The Zone P0 of Smit (1982) and Berggren *et al.* (1995) is absent in sections studied in north and central-eastern Mexico due to a short hiatus at top of the clastic unit. However, this subzone has been identified at the Bochil section above the clastic unit (Arenillas *et al.* 2002).

Similar species ranges in all K-Pg sections were recognized (Molina *et al.* 1998; Arenillas 2000; Arenillas *et al.* 2002). The stratigraphical distribution of the morphospecies at the Aïn Caravaca and Settara reference sections are shown in Figures 2 and 3. We use FAD (= first appearance datum) and LAD (= last appearance datum) for the biostratigraphical data.

Berggren *et al.* (1995) placed the K-Pg boundary at 65 Ma and the top of Chron C29r (calibration A) at 64.745 Ma. Röhl *et al.* (2001) used an astronomical calibration and reached to a different Danian scale-time i.e. 65.5 Ma for the K-Pg boundary and 65.2 Ma for the top of Chron C29r (calibration B). We used the biostratigrahic data from Molina *et al.* (1996, 1998) and the magnetostratigraphic data of Groot *et al.* (1989) at Agost to establish a high-resolution biomagnetostratigraphic correlation, calculate its rate sedimentation and calibrate the FADs and LADs of the species at Agost (Fig. 5). At this section, the sedimentation rate between the K-Pg boundary and the top of C29r was 0.76 cm/ky (for calibration A) or 0.65 cm/ky (for calibration B). From these estimates an approximate age of the first appearances and last appearances of the index species were obtained (see Fig. 5). The boundary clay sedimentation at Agost was surely slower than 0.76 or 0.65 cm/ky and the appearance of *Parvularugoglobigerina longiapertura* and *Parvularugoglobigerina eugubina* occurred later than those proposed in Figure 5. However, these estimates are used in the lack of a better calibration.

A similar biomagnetostratigraphic correlation and calibration can be established at Caravaca and Zumaya (Arenillas *et al.* 2002). The sedimentation rate in the boundary clay of both sections must be very similar to the one in Agost and probably less than 0.8 cm/ky, because the boundary clay and the *Guembelitria cretacea* Zone have the same thickness in the three sections. Except for the boundary clay their sedimentation rates were higher than at Agost. According to the biostratigraphic and magnetostratigraphic data at both sections (Roggenthen 1976; Smit 1982; Arenillas *et al.* 1998; Arz *et al.* 2000) the average sedimentation rate between the K-Pg boundary and the top of C29r was approximately 1.76 (A)–1.50 (B) cm/ky at Caravaca and 1.56 (A)–1.33 (B) cm/ky at Zumaya. The estimated age for the first appearance of the index species and in accordance with biomagnetostratigraphic calibrations at Agost, Caravaca and Zumaya is summarized in Figure 5.

New and revised lowermost Danian planktic foraminifer biozonation

Previous planktic foraminiferal zonations (Toumarkine & Luterbacher, 1985; Berggren *et al.*, 1995; Canudo *et al.* 1991; Molina *et al.* 1996; Apellaniz *et al.* 1997) are not detailed enough to precisely place and correlate the main palaeobiological and evolutionary events in the lowermost Danian. Other most detailed biozonations (Smit & Romein 1985; Keller 1993; Keller *et al.* 1995) are difficult to use in the present work because of different taxonomic interpretations (see Arenillas & Arz 2000). In order to establish a more detailed biozonation for the lower Danian and to maintain the most widely used zones a new subzonation is proposed. The Molina *et al.* (1996) zonation was a slight modification of the Bolli (1966) and Toumarkine & Luterbacher (1985) biozonations and included three biozones: the *Guembelitria cretacea* Zone, the *Parvularugoglobigerina eugubina* Zone and the *Parasubbotina pseudobulloides* Zone. The index-

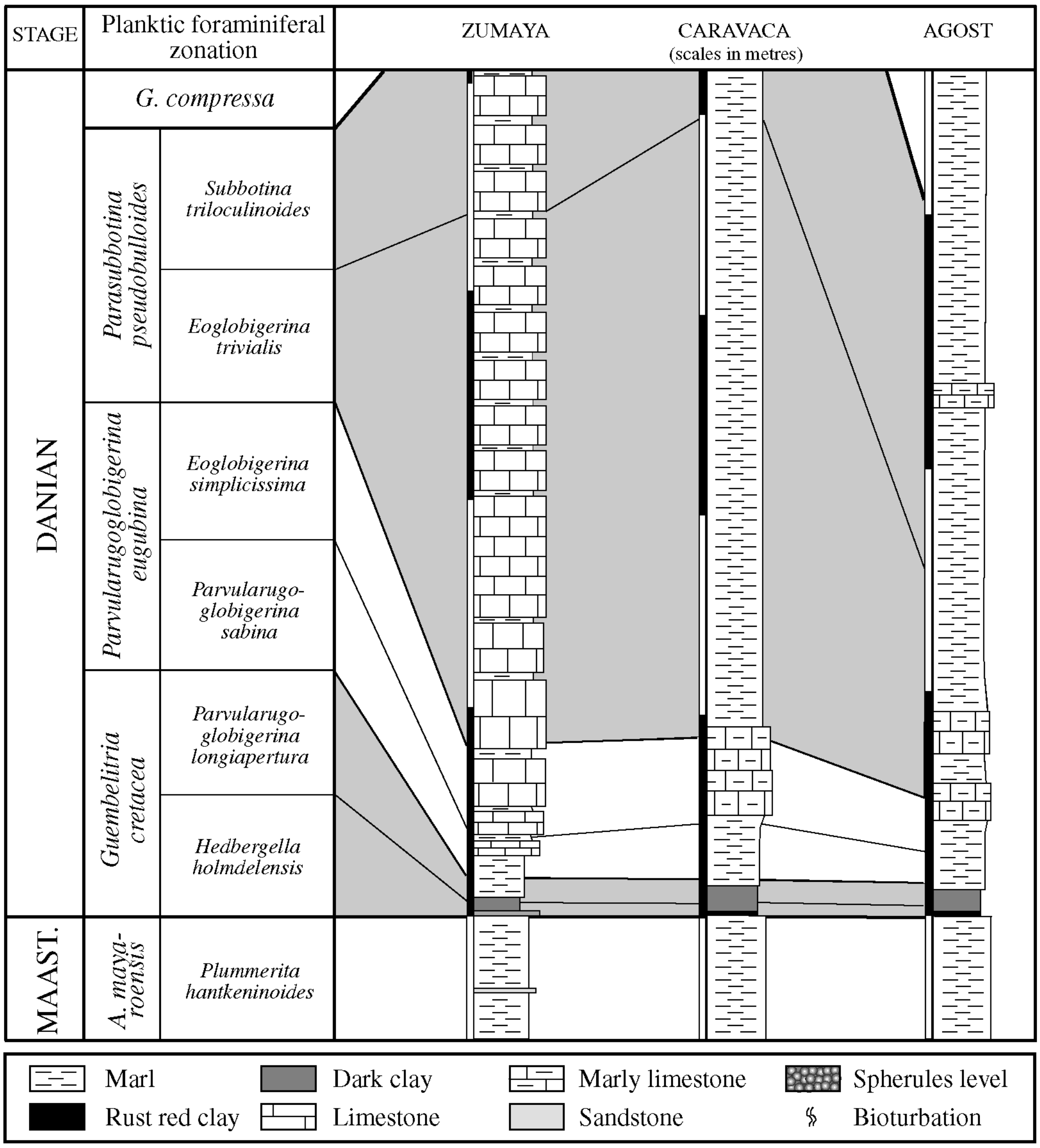

Fig. 7. Biozonation and correlation of the Spanish sections of Zumaya, Caravaca and Agost.

species used to subdivide these biozones are maintained because these taxa are abundant and easy to recognize. The LADs of *Plummerita hantkeninoides* and *Abathomphalus mayaroensis* and the FADs of *Parvularugoglobigerina longiapertura, Parvularugoglobigerina eugubina, Eoglobigerina simplicissima, Parasubbotina pseudobulloides, Subbotina triloculinoides* and *Globanomalina compressa* are used for the definition of the biozones and subzones (Figs. 4, 6).

Figure 6 shows the comparison of this new biozonation with other biozonations. The thickness of the biozones and subzones in different sections are given in Figures 7, 8 and 9. All zones are interval zones. The given names of the interval zones in the present paper derive from a single taxon, which is well represented in the interval.

The *Globanomalina compressa* Zone is above the *Parasubbotina pseudobulloides* Zone and was initially proposed by Molina *et al.* (1996). Blow (1979) and Berggren *et al.* (1995) however used the FAD of *Globanomalina compressa* in their definition of subzones. The zonation used here for the uppermost Maastrichtian follows Arz & Molina (2002), who subdivided the *Abathomphalus mayaroensis* Zone into three subzones. Of these, the *Plummerita hantkeninoides* Subzone is present just below the Danian *Guembelitria cretacea* Zone (about the last 200 ky of the Maastrichtian). The FAD of *Plummerita hantkeninoides* was used to define the base of this subzone (Ion 1993). The figures only include the upper part of the *Plummerita hantkeninoides* Subzone and the lower part of the *Globanomalina compressa* Zone.

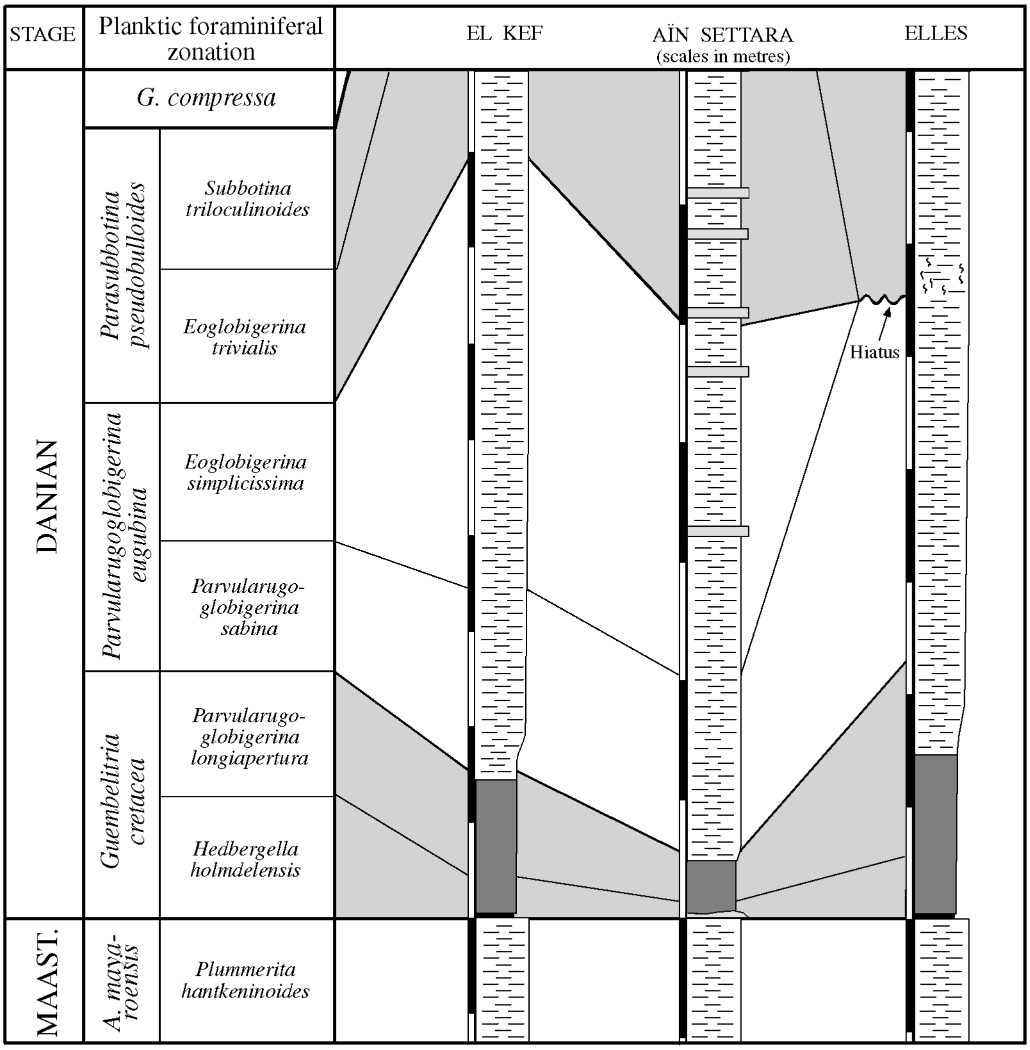

Fig. 8. Biozonation and correlation of the Tunisian sections of El Kef, Aïn Settara and Elles.

Guembelitria cretacea Interval Zone (Smit 1982)

Definition. – The interval between the LADs of *Plummerita hantkeninoides* and *Abathomphalus mayaroensis* and the FAD of *Parvularugoglobigerina eugubina.*

Magnetostratigraphic position. – Chron C29r.

Estimated age. – (A)≈65.000–64.981 Ma; (B)≈65.500–65.478 Ma.

Duration. – ≈18.4–21.5 ky.

Remarks. – This biozone was defined by Smit (1982) and the interval between the LADs of *Plummerita hantkeninoides* and *Abathomphalus mayaroensis* is precisely at the K-Pg boundary. Smit (1982) discovered an earlier tertiary planktic foraminiferal association at Caravaca (Spain) below the *Globigerina eugubina* Biozone established by Luterbacher & Premoli Silva (1964). Smit (1982) named it Zone P0 (= *Guembelitria cretacea* Zone) and defined it between the K-Pg boundary and to the FAD of *Globigerina minutula* (= *Globoconusa*? *alticonusa* in this paper and *Parvularugoglobigerina extensa* of Olsson *et al.* 1999).

Bolli (1966), Stainforth *et al.* (1975) and Toumarkine & Luterbacher (1985) did not define any zone for this lowermost Danian interval. They placed the base of the *Globigerina eugubina* Zone at the FAD of *Parvularugoglobigerina eugubina*, which does not coincide with the K-Pg boundary.

The *Guembelitria cretacea* Zone proposed here is not equivalent to the Zone P0 of Keller (1988), Berggren *et al.* (1995) and Berggren & Norris (1997). These authors considered *Parvularugoglobigerina eugubina* to be a senior synonymy of *Parvularugoglobigerina longiapertura*. The *Guembelitria cretacea* Zone is not exactly equivalent to Keller (1993) and Keller *et* *al.* (1995) P0 Zone. Although both species were taxonomically differentiated their ranges were considered to be similar and used to define the base of this biozone leading to an uncertain position. Subsequent biostratigraphic studies have demonstrated that *Parvularugoglobigerina longiapertura* appears earlier than *Parvularugoglobigerina eugubina* (Arenillas & Arz 1996; Molina *et al.* 1998; Arenillas *et al.* 2000a).

The FAD of *Parvularugoglobigerina longiapertura* allows for a subdivision of the *Guembelitria cretacea* Biozone into the following two subzones:

Hedbergella holmdelensis Interval Subzone (new)

Definition. – Interval between the LAD of *Plummerita hantkeninoides* to the FAD of *Parvularugoglobigerina longiapertura*.

Magnetostratigraphic position. – Chron C29r.

Estimated age. – (A)≈65.000–64.994 Ma; (B)≈65.500–65.493 Ma.

Duration. – ≈5.7–6.7 ky.

Reference section. – The Aïn Settara section, Tunisia (Fig. 1, loc. 4; for the description of this section see Arenillas *et al.* 2000b and Dupuis *et al.*2001). The base of the zone is at 0 m and the top is 0,16 m above the K-Pg boundary.

Distribution. – The highest thickness for this subzone has been found at El Kef and Elles (50 cm thick), which is much higher than at Aïn Settara (16 cm). Elsewhere the thickness of this subzone varies from 5 cm at the Caravaca and Zumaya sections to 4 cm at the Agost section. The subzone is characterised by a post-K-Pg boundary clay in Tethyan sections. The subzone has not been identified in Mexico – except at the Bochil section – although the typical 'post-K-Pg boundary cocktail units' must be included here.

Characteristic planktic foraminifera. – *Guembelitria cretacea, Guembelitria* cf. *trifolia, Hedbergella monmouthensis, Hedbergella holmdelensis, Heterohelix globulosa* and *Heterohelix navarroensis. Guembelitria cretacea* and *Guembelitria* cf. *trifolia* are the dominant species. The subzone corresponds with the Acme-Stage 1 proposed by Arenillas *et al.* (1998), which is characterized by the acme of *Guembelitria* that occurred just after the K-Pg boundary.

Remarks. – The LAD of *Plummerita hantkeninoides* is precisely at the K-Pg boundary. The *Hedbergella holmdelensis* Subzone is equivalent to the *Guembelitria cretacea* Zone *sensu* Canudo *et al.* (1991) and Apellaniz *et al.* (1997) and to the Zone P0 of Keller (1993), Keller *et al.* (1995), Berggren *et al.* (1995) and Berggren & Norris (1997). Smit (1982) placed the top of the Zone P0 at the FAD of *Globigerina minutula* (= *Globoconusa alticonusa* in this paper), which is a biohorizon close to the FAD of *Parvularugoglobigerina longiapertura*. Therefore, Zone P0 of Smit (1982) is virtually similar to the *Hedbergella holmdelensis* Subzone. *Hedbergella holmdelensis* Olsson is used as nominate species for the subzone, because this morphospecies is very probable a post-K-Pg survivor. Like *Guembelitria cretacea* it probably played a significant role in the phylogeny of Danian taxa (Olsson & Liu 1993; Arenillas & Arz 1996; Berggren & Norris 1997; Olsson *et al.* 1999; Arenillas 2000).

Parvularugoglobigerina longiapertura Interval Subzone (new)

Definition. – The interval from the FAD of *Parvularugoglobigerina longiapertura* to the FAD of *Parvularugoglobigerina eugubina*.

Magnetostratigraphic position. – Chron C29r.

Estimated age. – (A)≈64.994–64.981 Ma; (B)≈65.493–65.478 Ma.

Duration. – ≈12.7–14.8 ky.

Reference section. – The Aïn Settera section in Tunisia (Fig. 1, loc. 4; for the description of this section see Arenillas *et al.* 2000b and Dupuis *et al.* 2001). The base of the zone is at 0.16 m above the K-Pg boundary at the Aïn Settera section.

Distribution. – The thickness of this subzone varies from 180 cm at the Elles section to 130 cm at El Kef and 45 cm at Aïn Settara and Coxquihui sections.

Characteristic planktic foraminifera. – *Parvularugoglobigerina longiapertura, Parvularugoglobigerina umbrica, Parvularugoglobigerina perexigua, Globoconusa*? *alticonusa, Globoconusa*? *fodina, Globoconusa*? cf. *fringa, Woodringina claytonensis, Guembelitria cretacea, Guembelitria* cf. *trifolia, Guembelitria danica, Guembelitria irregularis* and *Guembelitria*? *alabamensis*.

Guembelitria cretacea and *Guembelitria* cf. *trifolia* are abundant in the lower part of the subzone, whereas *Parvularugoglobigerina longiapertura, Parvularugoglobigerina umbrica, Globoconusa*? *alticonusa* and *Globoconusa*? *fodina* dominate the upper part. The transition between the Acme-Stages 1 and 2 (i.e. Arenillas *et al.* 1998) and dominated respectively by *Guembelitria* and *Parvularugoglobigerina-Globoco-*

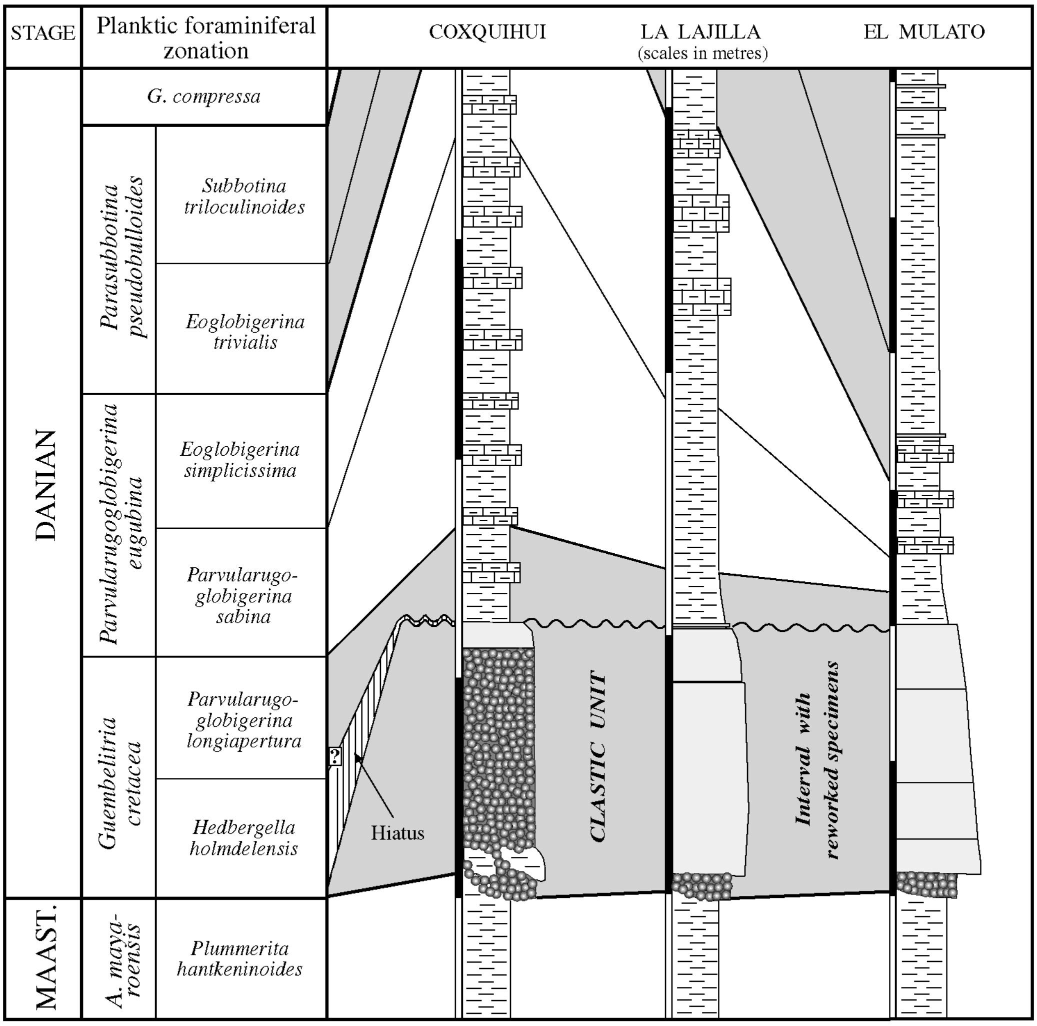

Fig. 9. Biozonation and correlation of the Mexican sections of Coxquihui, La Lajilla and El Mulato.

nusa? is recorded from this subzone. The dominant species of *Parvularugoglobigerina* (*Parvularugoglobigerina longiapertura* and *Parvularugoglobigerina umbrica*) have higher-arched aperture, compressed chambers and high number of chambers in the last whorl (Smit 1982).

Remarks. – Blow (1979) followed by Canudo *et al.* (1991) and Apellaniz *et al.* (1997) used the FAD of *Parvularugoglobigerina longiapertura* to characterize the base of their *Parvularugoglobigerina longiapertura* Zone. This species has a very distinct and stable morphology with compressed test and high slit-like aperture. The base of the subzone coincides with the decline of the possible survivors of Cretaceous species above the K–Pg boundary and the beginning of the radiation of tertiary species. *Parvularugoglobigerina longiapertura* is one of the first tertiary species to appear. Keller (1988), Berggren *et al.* (1995) and Berggren & Norris (1997) may have used the FAD of *Parvularugoglobigerina longiapertura*, because the synonymy of *Parvularugoglobigerina eugubina* and *Parvularugoglobigerina longiapertura* (Smit 1982) has generally been accepted.

Parvularugoglobigerina eugubina Interval Zone

(Luterbacher & Premoli Silva (1964) identified as the *Globigerina eugubina* Zone; emended Bolli 1966)

Definition. – The interval from the FAD of *Parvularugoglobigerina eugubina* to the FAD of *Parasubbotina pseudobulloides.*

Magnetostratigraphic position. – Chron C29r.

Estimated age. – (A)≈64.981–64.945 Ma; (B)≈65.478–65.436 Ma.

Duration. – ≈35.7–41.9 ky.

Discussion. – Luterbacher and Premoli Silva (1964) introduced the interval zone based on the faunal succession at the Gubbio section in Italy, where the zone is characterised by the presence of *Parvularugoglobigerina eugubina*. Later, the lower boundary was formally defined at the FAD of *Parvularugoglobigerina eugubina* (Bolli 1966). Most specialists have adopted this definition (Stainforth *et al.* 1975; Blow 1979; Toumarkine & Luterbacher 1985; Keller 1993; Berggren *et al.* 1995; Berggren & Norris 1997).

However, the *Guembelitria cretacea* Zone is not present in the Italian sections (Gubbio, Ceselli, etc.) and Luterbacher & Premoli Silva (1964), Bolli (1966), Stainforth *et al.* (1975) and Toumarkine & Luterbacher (1985) placed the FAD of *Parvularugoglobigerina eugubina* and the base of the biozone at the K-Pg boundary.

Arenillas & Arz (2000) distinguished taxonomically between *Parvularugoglobigerina eugubina* and *Parvularugoglobigerina longiapertura* by reviewing the holotype of *Parvularugoglobigerina eugubina* and inspection of specimens from the type horizon of the *Globigerina eugubina* Zone at the Ceselli type section in Italy. In contrast with *Parvularugoglobigerina longiapertura, Parvularugoglobigerina eugubina* is characterized by having a lower-arched aperture as also indicated by Stainforth *et al.* (1975) and Toumarkine & Luterbacher (1985).

Parvularugoglobigerina eugubina sensu lato has been used as the nominate taxon for this zone (e.g. Bolli 1966; Berggren & Norris 1997), but Molina *et al.* (1996) and Arenillas & Arz (2000) recommend to re-establish the original taxonomic concept of *Parvularugoglobigerina eugubina* and use its FAD as the base of this biozone.

The top of this biozone is not exactly equivalent to top of the Zone P1a of Keller (1993), who used the FAD of *Parasubbotina pseudobulloides* to subdivide the biozone into P1a (1) and P1a (2) subzones (Fig. 6). The top of the biozone does not correspond to top of the Pα Zone of Berggren *et al.* (1995) because they defined the *Parvularugoglobigerina eugubina* Zone as a total range zone.

We follow Bolli (1966), Toumarkine & Luterbacher (1985) and Berggren & Miller (1988) and use the FAD of *Parasubbotina pseudobulloides* as the marker for the base of the next biozone. The reason to this is that the LAD of *Parvularugoglobigerina eugubina* is a biohorizon, which can be difficult to recognize, since juvenile specimens of *Globanomalina* and/or *Praemurica* species easily can be confused with *Parvulagoglobigerina eugubina*.

Smit and Romein (1985) divide this biozone into five subzones (I to V). They used the FADs of respectively *Globigerina minutula* (= *Globoconusa*? *alticonusa*), *Globigerina fringa* (= *Globoconusa*? cf. *fringa*), *Globigerina eugubina* (= *Parvularugoglobigerina eugubina*), *Eoglobigerina taurica* (= *Praemurica taurica*) and the large flat *Globigerina eugubina* (=? *Globanomalina archeocompressa*) to define the bases of the subzones I to V. Some of these biostratigraphic datums are similar to those used in present subzonation, such as the FAD of *Globoconusa*? *alticonusa* with respect to the FAD of *Parvularuglobigerina longiapertura*; however, others are more uncertain from the taxonomic and biostratigraphic points of view and are not considered further in this study.

Eoglobigerina simplicissima is the first Danian species with a cancellated wall. The FAD of this species is used to subdivide the *Parvularugoglobigerina eugubina* Zone into the following two subzones:

Parvularugoglobigerina sabina Interval Subzone (new)

Definition. – The interval ranging from the FAD of *Parvularugoglobigerina eugubina* to the FAD of *Eoglobigerina simplicissima.*

Magnetostratigraphic position. – Chron C29r.

Estimated age. – (A)≈64.981–64.966 Ma; (B) between 65.478–65.460 Ma.

Duration. – ≈15.0–17.6 ky.

Reference section. – The Aïn Settara section, Tunisia (Fig. 1 loc. 4; for a description of the section, see Arenillas *et al.* 2000b and Dupuis *et al.* 2001). The base of the subzone is 0.61 m above the K-Pg boundary in the section and the top of the subzone is 2.1 m above the K-Pg boundary.

Distribution. – The thickest representative of this subzone is at Elles (2.95 m thick). Elsewhere the subzone is thinner i.e. El Kef (170 cm), Aïn Settara (150 cm), La Lajilla (49 cm), Coxquihui (36 cm), El Mulato (35 cm) and Caravaca (31 cm).

Characteristic planktic foraminifera. – Parvularugoglobigerina eugubina, Parvularugoglobigerina sabina, Parvularugoglobigerina perexigua, Parvularugoglobigerina longiapertura, Parvularugoglobigerina cf. *hemisphaerica, Globoconusa*? *alticonusa, Globoconusa*? *fodina, Globoconusa*? cf. *fringa, Globoconusa*? *minutula, Globoconusa*? *extensa, Woodringina claytonensis, Woodringina hornerstownensis, Chiloguembelina morsei, Chiloguembelina midwayensis, Guembelitria cretacea, Guembelitria* cf. *trifolia, Guembelitria danica, Guembelitria irregularis* and *Guembelitria*? *alabamensis.*

The dominant species are *Parvularugoglobigerina eugubina, Parvularugoglobigerina sabina, Parvularugoglobigerina longiapertura, Parvularugoglobigerina perexigua, Globoconusa*? *fodina* and *Globoconusa*? cf. *fringa*. The subzone approximately corresponds with the Acme-Stage 2 (Arenillas *et al.* 1998). The Acme-Stage 2 is characterised by the acme of *Parvularugoglobigerina* and *Globoconusa*? The parvularugoglobigerinids with higher-arched aperture (*Parvularugoglobigerina longiapertura, Parvularugoglobigerina perexigua*) and lower-arched aperture (*Parvularugoglobigerina eugubina, Parvularugoglobigerina sabina*) have a similar abundance, but nearly all them present globular chambers in contrast with the preceding subzone.

Remarks. – Arenillas and Arz (2000) have differentiated *Parvularugoglobigerina eugubina* from *Parvularugoglobigerina sabina* after inspection of the holotypes. Stainforth *et al.* (1975), Toumarkine & Luterbacher (1985), Berggren & Norris (1997) and Olsson *et al.* (1999) considered *Parvularugoglobigerina sabina* as a junior synonym of *Parvularugoglobigerina eugubina*.

Parvularugoglobigerina sabina is used here as the nominate species of the subzone, because its FAD is just below the FAD of *Parvularugoglobigerina eugubina*. It is an abundant and distinctive species characterized by an intraumbilical aperture and a moderately elevated trochospiral test. In contrast *Parvularugoglobigerina eugubina* has an umbilical-extraumbilical aperture and very low trochospiral test (Arenillas 2000; Arenillas & Arz 2000). The last two diagnostic differences have been frequently used in the differentiation of species and even genera such as *Eoglobigerina* and *Parasubbotina* (Berggren & Norris 1997; Olsson *et al.* 1999). Arenillas & Arz (2000) therefore suggested *Parvularugoglobigerina eugubina* and *Parvularugoglobigerina sabina* as distinct species.

Eoglobigerina simplicissima Interval Subzone (new)

Definition. – The interval between the FAD of *Eoglobigerina simplicissima* and the FAD of *Parasubbotina pseudobulloides*.

Magnetostratigraphic position. – Chron C29r.

Estimated age. – ≈ (A) between 64.966–64.945 Ma; (B) between 65.460–65.436 Ma;

Duration. – ≈20.7–24.3 ky.

Reference section. – The Aïn Settara section, Tunisia (Fig. 1, loc. 4). The base of the subzone is 2,1 m above the K-Pg boundary and the top of the subzone is 5,1 m above the K-Pg boundary at Aïn Settara section.

Distribution. – The highest thickness for this subzone is at El Kef (3.50 m) and Aïn Settara (3.00 m) followed by Coxquihui section (2.45 m), La Lajilla section (1.16 m) and Zumaya section (40 cm).

Characteristic planktic foraminifera. – *Parvularugoglobigerina eugubina, Parvularugoglobigerina sabina, Parvularugoglobigerina* cf. *hemisphaerica, Globanomalina archeocompressa, Globanomalina imitata, Globoconusa*? *alticonusa, Globoconusa*? *minutula, Globoconusa*? *extensa, Eoglobigerina simplicissima, Eoglobigerina eobulloides, Eoglobigerina praeedita, Parasubbubbotina moskvini, Woodringina claytonensis, Woodringina hornerstownensis, Chiloguembelina morsei, Chiloguembelina midwayensis, Guembelitria cretacea, Guembelitria* cf. *trifolia, Guembelitria danica, Guembelitria irregularis* and *Guembelitria*? *alabamensis*.

Parvularugoglobigerina eugubina, Parvularugoglobigerina sabina, Globoconusa? cf. *fringa* and *Globoconusa*? *fodina* are the dominant species in the lower part of the subzone and *Woodringina hornerstownensis* and *Chiloguembelina morsei* dominate the upper part. The transition between Acme-Stages 2 and 3 proposed by Arenillas *et al.* (1998) occurs in this subzone, and is dominated first by *Parvularugoglobigerina-Globoconusa*? and then by *Woodringina-Chiloguembelina*. *Parvularugoglobigerina eugubina* and *Parvularugoglobigerina sabina* are the dominant species of *Parvularugoglobigerina* and they are characterized by having a lower-arched aperture.

Remarks. – Smit (1982), Smit & Romein (1985) and Keller 1988) proposed a similar subdivision of the *Parvularugoglobigerina eugubina* Zone. Their subdivision was based on the first appearance of *Eoglobigerina* species with cancellated wall-texture such as the FAD of *Eoglobigerina taurica* (= *Praemurica taurica* in this paper). The *Eoglobigerina simplicissima* Subzone corresponds to subzones IV and V of Smit & Romein (1985). The planktic foraminifers reach normal size in the lower part of this subzone and thus can be found in the fraction larger than 150 microns. Keller (1988) made a similar observation at the El Kef section.

Eoglobigerina simplicissima Blow is used as the name the subzone, because this species has a characteristic and more stable morphology than *Eoglobigerina eobulloides* has. Both species were considered to be synonymous by Olsson *et al.* (1999). Arenillas (2000) however considered the taxa as distinct species, because *Eoglobigerina simplicissima* only has 3.5 to 4 chambers in the last whorl and it is the ancestor of the *Eoglobigerina microcellulosa-Subbotina* lineage. *Eoglo-*

bigerina eobulloides has 4 to 4.5 chambers and it is the ancestor of the *Eoglobigerina praedita-Eoglobigerina edita-Eoglobigerina pentagona* lineage and the *Eoglobigerina fringa-Parasubbotina* lineage.

Parasubbotina pseudobulloides Interval Zone

(Leonov & Alimarina (1961) as *Globigerina pseudobulloides-Globigerina daubjergensis* Zone; Bolli (1966) shortened this name; the zone was emended by Molina *et al.* (1996)).

Definition. – The interval between the FAD of *Parasubbotina pseudobulloides* and FAD of *Globanomalina compressa.*

Magnetostratigraphic position. – Chron C29r–Chron C29n.

Estimated age. – (A)≈64.945–64.545 Ma; (B)≈65.436–64.973 Ma.

Duration. – ≈400.3–463.4 ky.

Remarks. – *Parasubbotina pseudobulloides* is the index taxon that has been used in most biozonations (Luterbacher & Premoli Silva 1964; Bolli 1966; Smit 1982; Toumarkine & Luterbacher 1985). Molina *et al.* (1996) subdivided the zone into two biozones namely the *Parasubbotina pseudobulloides* and *Globanomalina compressa* zones, where the latter was based on the FAD of *Globanomalina compressa*. Blow (1979) defined the base of his *Globanomalina (T.) compressa/Globanomalina (T.) eobulloides simplicissima* (P1b) Subzone on the basis of the first appearance of *Globanomalina compressa*. Berggren *et al.* (1995) and Berggren & Norris (1997) used the same first appearance, which they considered it to be similar to the FAD of *Praemurica inconstans* and *Acarinina trinidadensis*. This is in contrast with the interpretation of Toumarkine & Luterbacher (1985) and the biostratigraphic data reported here.

Following Berggren *et al.* (1995) the FAD of *Subbotina triloculinoides* is used to subdivide the *Parasubbotina pseudobulloides* Zone into the following two subzones:

Eoglobigerina trivialis Interval Subzone (new name)

Definition. – The interval from the FAD of *Parasubbotina pseudobulloides* to the FAD of *Subbotina triloculinoides.*

Magnetostratigraphic position. – Chron C29r.

Estimated age. – (A)≈64.945–64.774 Ma; (B)≈65.436–65.235 Ma.

Duration. – ≈171.5–201.1 ky.

Reference section. – The Caravaca section, Spain (Fig. 1, loc. 2; for description of the section see Aarz *et al.* 2000). The base of the subzone is 0.8 m above the K-Pg boundary and the top of the subzone is 3.3 m above the K-Pg boundary at the Caravaca section.

Distribution. – The highest thickness for this subzone has been found at El Kef and Aïn Settara (probably more than 5 m). At Caravaca, Zumaya and Agost the subzone spans 3.23, 2.75 and 1.28 m respectively.

Characteristic planktic foraminifera. – *Globanomalina archeocompressa, Globanomalina imitata, Globanomalina planocompressa, Eoglobigerina simplicissima, Eoglobigerina eobulloides, Eoglobigerina praeedita, Eoglobigerina trivialis, Eoglobigerina microcellulosa, Eoglobigerina fringa, Parasubbotina moskvini, Parasubbotina pseudobulloides, Praemurica taurica, Praemurica pseudoincontans, Woodringina claytonensis, Woodringina hornerstownensis, Chiloguembelina morsei, Chiloguembelina midwayensis, Guembelitria cretacea, Guembelitria* cf. *trifolia, Guembelitria danica, Guembelitria irregularis* and *Guembelitria? alabamensis.*

The dominant species are *Woodringina hornerstownensis* and *Chiloguembelina morsei.* The subzone corresponds to the lower part of Acme-Stage 3 (Arenillas *et al.* 1998), which is characterized by the predominance of *Woodringina* and *Chiloguembelina. Parasubbotina pseudobulloides, Parasubbotina moskvini, Eoglobigerina simplicissima, Eoglobigerina trivialis, Globanomalina planocompressa, Praemurica taurica* and *Praemurina pseudoinconstans* are also frequent.

Remarks. – The defintion of the subzone corresponds to that of the *Subbotina pseudobulloides* Subzone of Berggren & Miller (1988).

The subzone is similar to Keller's (1993) P1b and P1c (1) subzones. These were defined respectively by the FAD's of *Parasubbotina varianta* and *Praemurica inconstans.* Both biohorizons are earlier than the FAD of *Subbotina triloculinoides.* The FAD of *Parasubbotina pseudobulloides* is similar to the LADs of *Parvularugoglobigerina* (*Parvularugoglobigerina eugubina*) and primitive *Globoconusa* (*Globoconusa? extensa* and *Globoconusa? alticonusa*), and coincides with an increase of species with cancellated walled-texture.

Subbotina triloculinoides Interval Subzone (new)

Definition. – The interval from the FAD of *Subbotina triloculinoides* to the FAD of *Globanomalina compressa*.

Magnetostratigraphic position. – Chron C29r–Chron C29n.

Estimated age. – (A)≈64.774–64.545 Ma; (B)≈65.235–64.973 Ma.

Duration. – ≈228.8–262.3 ky.

Reference section. – The Caracaca section, Spain (Fig. 1, loc. 2). The base of the subzone is 3.3 m above the K-Pg boundary and the top of the subzone is 5.6 m above the K-Pg boundary at the Caravaca section.

Distribution. – The highest thickness of this subzone can be found at the Tunisian sections. At Caravaca, Zumaya and Agost it spans 4.00, 3.50 and 1.80 m respectively.

Characteristic planktic foraminifera. – Globanomalina archeocompressa, Globanomalina imitata, Globanomalina planocompressa, Eoglobigerina simplicissima, Eoglobigerina eobulloides, Eoglobigerina praeedita, Eoglobigerina edita, Eoglobigerina pentagona, Eoglobigerina trivialis, Eoglobigerina tetragona, Eoglobigerina microcellulosa, Eoglobigerina fringa, Subbotina triloculinoides, Parasubbotina moskvini, Parasubbotina pseudobulloides, Parasubbotina varianta, Praemurica taurica, Praemurica pseudoincontans, Praemurica inconstans, Woodringina claytonensis, Woodringina hornerstownensis, Chiloguembelina morsei, Chiloguembelina midwayensis, Guembelitria cretacea, Guembelitria cf. *trifolia* and *Guembelitria irregularis*.

Remarks. – As in the preceding subzone, the dominant species is *Woodringina hornerstownensis* and *Chiloguembelina morsei* (Acme-Stage 3 of Arenillas *et al.* 1998), but the abundance has decreased slightly. *Eoglobigerina trivialis, Eoglobigerina edita, Subbotina triloculinoides, Parasubbotina pseudobulloides, Parasubbotina varianta, Globanomalina planocompressa, Praemurica taurica* and *Praemuria inconstans* are frequent.

Berggren & Miller (1988) used the FAD of *Subbotina triloculinoides* as the biostratigraphic datum for the base of the P1b Zone. The subzone proposed here is not identical to Subzone P1b of Berggren *et al.* (1995). They considered the FAD of *Globanomalina compressa* (top of P1b) to be in C28n coinciding with the FAD of *Praemurica inconstans* (a datum that probably is equivalent to the FAD of *Acarinina trinidadensis* of Bolli (1966), Toumarkine & Luterbacher (1985) and Arenillas (2000)). Therefore, the *Subbotina triloculinoides* Subzone probably corresponds with the lower part of Zone P1b of Berggren *et al.* (1995) and Berggren & Norris (1997).

The *Subbotina triloculinoides* Subzone is similar to Keller's (1993) Zone P1c (2). The FAD of *Subbotina triloculinoides* approximately coincides with an increase in new species characterized by having cancellate wall-texture and related to *Parasubbotina, Eoglobigerina, Subbotina* and *Praemurica*, and 'smooth' walled-texture pertaining to *Globanomalina*.

Conclusions

A new biosubzonation mostly based on Spanish, Tunisian and Mexican sections is proposed and it is considered valid for low and middle latitudes. The following zones and subzones are emended or newly established: (1) The *Guembelitria cretacea* Zone, which is subdivided into the *Hedbergella holmdelensis* and *Parvularugoglobigerina longiapertura* subzones; (2) The *Parvularugoglobigerina eugubina* Zone with the *Parvularugoglobigerina sabina* and *Eoglobigerina simplicissima* subzones, and (3) the *Parasubbotina pseudobulloides* Zone with the *Eoglobigerina trivialis* and *Subbotina triloculinoides* subzones.

To subdivide the biozones, we have chosen easily recognizable and abundant index-species whose appearances coincided with significant foraminifer evolutionary events. The LADs of *Plummerita hantkeninoides* and *Abathomphalus mayaroensis* and the FADs of *Parvularugoglobigerina longiapertura, Parvularugoglobigerina eugubina, Eoglobigerina simplicissima, Parasubbotina pseudobulloides, Subbotina triloculinoides* and *Globanomalina compressa* are used. The FADs of *Parvularugoglobigerina eugubina* and *Parasubbotina pseudobulloides* correspond with the base of the previous biozones of the same name. The FAD of *Parvularugoglobigerina longiapertura* approximately corresponds with the lowest record of tertiary species. Finally, the FADs of *Eoglobigerina simplicissima* and *Subbotina triloculinoides* coincide with the lowest record of *Eoglobigerina* (first genus with cancellate wall) and *Subbotina*, respectively.

The biostratigraphic data used to define the new biozones and subzones are isochrone, at least in Tethys, North Atlantic and Gulf of Mexico.

Acknowledgements. – We thank Robert Speijer, Jan A. Rasmussen and an anonymous referee for their valuable revisions of the manuscript. We are grateful to Morris Villarroel (PhD in Biology, McGill University, Canada) for correcting the English. This research was funded by DGES project BTE-2001-1809, DGA Group and project P131/2001 and Universidad de Zaragoza project UZ2001-CIEN-01.

References

Alegret, L., Molina, E. & Thomas, E. 2001a: Benthic foraminifera at the Cretaceous/Tertiary boundary around the Gulf of Mexico. *Geology 29 (10)*, 891–894.

Alegret, L., Arenillas, I., Arz, J.A. & Meléndez, A. 2001b: Reconstrucción paleoambiental del tránsito Cretácico-Terciario en La Lajilla (México) con foraminíferos. *Geogaceta 30*, 23–26.

Alegret, L., Arenillas, I., Arz, J.A., Liesa, C., Meléndez, A., Molina, E., Soria, A.R. & Thomas, E. 2002: The Cretaceous / Tertiary boundary: sedimentology and micropalaeontology at El Mulato section, NE Mexico. *Terra Nova 14 (5)*, 330–336.

Apellaniz, E., Baceta, J.I., Bernaola-Bilbao, G., Núñez-Betelu, K., Orue-etxebarria, X., Payros, A., Pujalte, V., Robin, E. & 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 Société géologique de France 168 (6)*, 783–793.

Arenillas, I. 2000: *Los foraminíferos planctónicos del Paleoceno-Eoceno inferior: Sistemática, Bioestratigrafía, Cronoestratigrafía y Paleoceanografía*. 513 pp. Doctoral Thesis (dissertation in 1996), Prensas Universitarias de Zaragoza, Spain.

Arenillas, I. & Arz, J.A. 1996: Origen y filogenia de las primeras especies de foraminíferos planctónicos del Paleoceno basal, tras el límite Cretácico/Terciario. *Boletín de la Real Sociedad Española de Historia Natural, Tomo Extraordinario,* 267–271.

Arenillas, I. & Arz, J.A. 2000: *Parvularugoglobigerina eugubina* type-sample at Ceselli (Italy): planktic foraminiferal assemblage and lowermost Danian biostratigraphic implications. *Rivista Italiana di Paleontologia e Stratigrafia 106 (3)*, 379–390.

Arenillas, I., Arz, J.A. & 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 (1–2)*, 127–138.

Arenillas, I., Arz, J.A., Molina, E. & Dupuis, C. 2000a: An independent test of planktic foraminiferal turnover across the Cretaceous/Paleogene (K/P) boundary at El Kef, Tunisia: Catastrophic mass extinction and possible survivorship. *Micropaleontology 46 (1)*, 31–49.

Arenillas, I., Molina, E., Arz, J.A. & Dupuis, C. 2000b: The Cretaceous/Paleogene (K/P) boundary at Aïn Settara, Tunisia: sudden catastrophic mass extinction in planktic foraminifera. *Journal of Foraminiferal Research 30 (3)*, 202–218.

Arenillas, I., Alegret, L., Arz, J.A., Mélendez, A., Molina, E., Liesa, C., Soria, A.R., Cedillo-Pardo, E., Grajales-Nishimura, J.M. & Rosales, M.C. 2002: Cretaceous/Tertiary boundary planktic foraminiferal mass extinction and biochronology at La Ceiba, Bochil (México) and El Kef stratotype (Tunisia): Timing of K/T units deposition. *Geological Society of America Special Paper 356*, 253–263.

Arz, J.A. & Arenillas, I. 1998: Foraminíferos planctónicos en el límite Cretácico/Terciario del Pirineo occidental (España): Bioestratigrafía, Análisis cuantitativo y Tafonomía. *Revista de la Sociedad Mexicana de Paleontología 8 (2)*, 146–162.

Arz, J. A. & Molina, E. 2002: Bioestratigrafía y cronoestratigrafía con foraminíferos planctónicos del Campaniense superior y Maastrichtiense de latitudes subtropicales y templadas (España, Francia y Tunicia). *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen 224 (2)*, 161–195.

Arz, J.A., Arenillas, I., Molina, E. & 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 (2)*, 251–268.

Arz, J.A., Arenillas, I., Molina, E. & Sepúlveda, R. 2000: La estabilidad faunística de 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 (1)*, 27–47.

Arz, J.A., Arenillas, I., Soria, A.R., Alegret, L., Grajales-Nishimura, J.M., Liesa, C., Mélendez, A., Molina, E. & Rosales, M.C. 2001a: Micropaleontology and Sedimentology across the Cretaceous/Tertiary boundary at La Ceiba (Mexico): impact-generated sediment gravity flows. *Journal of South American Earth Sciences 14 (5)*, 505–519.

Arz, J.A., Alegret, L., Arenillas, I., Liesa, C., Molina, E. & Soria, A.R. 2001b: Extinción de foraminíferos del límite Cretácico/Terciario en Coxquihui (México) y su relación con las evidencias de impacto. *Revista Española de Micropaleontología 33 (2)*, 221–236.

Barrera, E. & Keller, G. 1990: Stable isotope evidence for gradual environmental changes and species survivorship across the Cretaceous/Tertiary boundary. *Paleoceanography 5*, 867–890.

Berggren, W.A. & Miller, K.G. 1988: Paleogene tropical planktonic foraminiferal biostratigraphy and magnetobiochronology. *Micropaleontology 34 (4)*, 362–380.

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

Berggren, W.A., Kent, D.V., Swisher, III C.C. & Aubry, M.P. 1995: A revised Paleogene geochronology and chronostratigraphy. *In* Berggren, W.A. *et al.* (eds): *Geochronology, Time and Global Stratigraphic Correlation*, Society of Economic Geologist and Paleontologist, Special Publication, 1–392.

Blow, W.H. 1979: *The Cainozoic Globigerinidae. A study of the morphology, taxonomy, evolutionary relationship and the stratigraphical distribution of some Globigerinidae (mainly Globigerinacea)*. E. J. Brill (Ed.), *3 vols.*, 1–1413.

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)*, 1–34.

Bralower, T.J., Paull, C.K. & Leckie, R.M. 1998: The Cretaceous–Tertiary boundary cocktail: Chicxulub impact triggers margin collapse and extensive sediment gravity flows. *Geology 26*, 331–334.

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

D'Hondt, S. L. 1991: Phylogenetic and stratigraphic analysis of earliest Paleocene biserial and triserial planktonic foraminifera. *Journal of Foraminiferal Research 21 (2)*, 168–181.

Dupuis, C., Steurbaut, E., Molina, E., Rauscher, R., Tribovillard, N.P., Arenillas, I., Arz, J.A., Robaszynski, F., Caron, M., Robin, E., Rocchia, R. & Lefèvre, I. 2001: The Cretaceous–Paleogene (K/P) boundary in the Aïn Settara section (Kalaat-Senan, Central Tunisia): lithological, micropaleontological and geochemical evidence. *Bulletin de l'Institut Royal des Sciences Naturelles de Belgique 71*, 169–190.

Grajales-Nishimura, J.M., Cedillo-Pardo, E., Rosales-Domínguez, C., Morán-Zenteno, D.J., Alvarez, W., Claeys, P., Ruíz-Morales, J., García-Hernández, J., Padilla-Avila, P. & Sanchez-Ríos, A. 2000: Chicxulub impact: The origin of reservoir and seal facies in the southeastern Mexico oil fields. *Geology 28*, 307–310.

Groot, J.J., De Jonge, R.B.G., Langereis, C.G., Ten Kate, W.G.H.Z. & Smit, J. 1989: Magnetostratigraphy of the Cretaceous–Tertiary boundary at Agost (Spain). *Earth and Planetary Science Letters 94*, 385–397.

Huber, B.T. 1996: Evidence for planktonic foraminifer reworking versus survivorship across the Cretaceous–Tertiary boundary at high latitudes. *In* Ryder G. *et al.* (eds): *The Cretaceous–Tertiary event and other catastrophes in Earth History*, *Geological Society of America Special Paper 307*, 319–334.

Ion, J. 1993: Upper Cretaceous planktonic foraminiferal biostratigraphy from the Carpathians and northern Dobrogea (Romania) related to macropaleontological zonation. *Romanian Journal of Stratigraphy 75*, 41–53.

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. & 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, G.P. & Alimarina, V.P. 1961: Stratigraphy and foraminifera of Cretaceous-Paleogene 'transition' beds of the central part of the North Caucasus. *Moscow University Geology Faculty, sbornik Trudov*, 29–60.

Li, Q., McGowran, B. & Boersma, A. 1995: Early Paleocene *Parvularugoglobigerina* and late Eocene *Praetenuitella*: does evolutionary convergence imply similar habitat? *Journal of Micropaleontology 14*, 119–13.

Liu, C. & Olsson, R.K. 1992: Evolutionary radiation of microperforate planktonic foraminifera the K/T mass extinction event. *Journal of Foraminiferal Research 22 (4)*, 328–346.

Luterbacher, H.P. & Premoli Silva, I. 1964: Biostratigrafia del limite Cretaceo-Terziario nell'Appennino Centrale. *Rivista Italiana di Paleontologia e Stratigrafia 70*, 67–128.

MacLeod, N. 1993: The Maastrichtian-Danian radiation of triserial and biserial planktic foraminifera: Testing phylogenetic and adaptational hypotheses in the (micro) fossil record. *Marine Micropaleontology 21*, 47–100.

Molina, E., Arenillas, I. & Arz, J.A. 1996: The Cretaceous/Tertiary boundary mass extinction in planktic foraminifera at Agost (Spain). *Revue de Micropaléontologie 39 (3)*, 225–243.

Molina, E., Arenillas, I. & Arz, J.A. 1998: Mass extinction in planktic foraminifera at the Cretaceous/Tertiary boundary in subtropical and temperate latitudes. *Bulletin de la Société géologique de France 169 (3)*, 351–363.

Olsson, R.K. & Liu, C. 1993: Controversies on the placement of Cretaceous–Paleogene boundary and the K/P mass extinction of planktonic foraminifera. *Palaios 8*, 127–139.

Olsson, R.K., Hemleben, C., Berggren, W. & Liu, C. 1992: Wall texture classification of planktonic foraminifera genera in the Lower Danian. *Journal of Foraminiferal Research 22 (3)*, 195–213.

Olsson, R.K., Hemleben, C., Berggren, W. & Huber, C. 1999: Atlas of Paleocene Planktonic Foramnifera. *Smithsonian Contributions to Paleobiology 85*, 1–252.

Robin, E. & Rocchia, R. 1998: Ni-rich spinel at the Cretaceous-Tertiary boundary of El Kef, Tunisia. *Bulletin de la Société géologique de France 169 (3)*, 365–372.

Rocchia, R., Boclet, D., Bonté, P., Devineau, J., Jéhanno, C. & Renard, M. 1987: Comparaison des distributions de l'iridium observées à la limite Crétacé-Tertiaire dans divers sites européens. *Memoires de la Societé géologique de France 150*, 95–103.

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

Roggenthen, W.M. 1976: Magnetic Stratigraphy in of the Paleocene. A comparison between Spain and Italy. *Memorie de la Societa Geologica Italiana 15*, 73–82.

Smit, J. 1982: Extinction and evolution of planktonic foraminifera after a major impact at the Cretaceous/Tertiary boundary. *Geological Society of America Special Paper 190*, 329–352.

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

Smit, J., Roep, T.B., Alvarez, W., Montanari, A., Claeys, Ph., Grajales-Nishimura, J.M. & Bermudez, J. 1996: Coarse-grained, clastic sandstone complex at the K/T boundary around the Gulf of México: Deposition by tsunami waves induced by the Chicxulub impact? *Geological Society of America Special Paper 307*, 151–182.

Smith, Ch., C. & Pessagno, E. A. 1973: Planktonic foraminifera and Stratigraphy of the Corsicana Formation (Maastrichtian) North-Central Texas. *Cushman Foundation Foraminiferal Research Special Publication 112*, 1–68.

Soria, A.R., Liesa, C., Mata, P., Arz, J.A., Alegret, L., Arenillas, I. & Meléndez, A. 2001: Slumping and a sandbar deposit at the K/T boundary in the El Tecolote sector (northeastern Mexico): An impact-induced sediment gravity flow. *Geology 29 (3)*, 231–234.

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

Toumarkine, M. & Luterbacher, H.P. 1985: Paleocene and Eocene planktic foraminifera. *In* Bolli, H.M., Saunders, J.B. & Perch-Nielsen, K. (eds): *Plankton Stratigraphy*, 88–153. Cambridge University Press, Cambridge.