

The Cretaceous/Tertiary boundary at the Agost section (Alicante Province, Betic Cordillera)

Eustoquio **Molina**, Laia **Alegret**, Ignacio **Arenillas** and José Antonio **Arz**

Departamento de Ciencias de la Tierra, Facultad de Ciencias, Universidad de Zaragoza. E-50009 Zaragoza (Spain).

LOCATION AND STRATIGRAPHY

The Agost section is one of the most relevant and best known Spanish Cretaceous/Tertiary (K/T) sections. It is located in the Betic Cordillera of southeastern Spain. The outcrop is placed about 1 km north of the village of Agost, in Alicante province. The Cretaceous/Tertiary transition can be sampled in a road cut near the 13 km marker post of the Agost-Castalla road (Fig. 1).

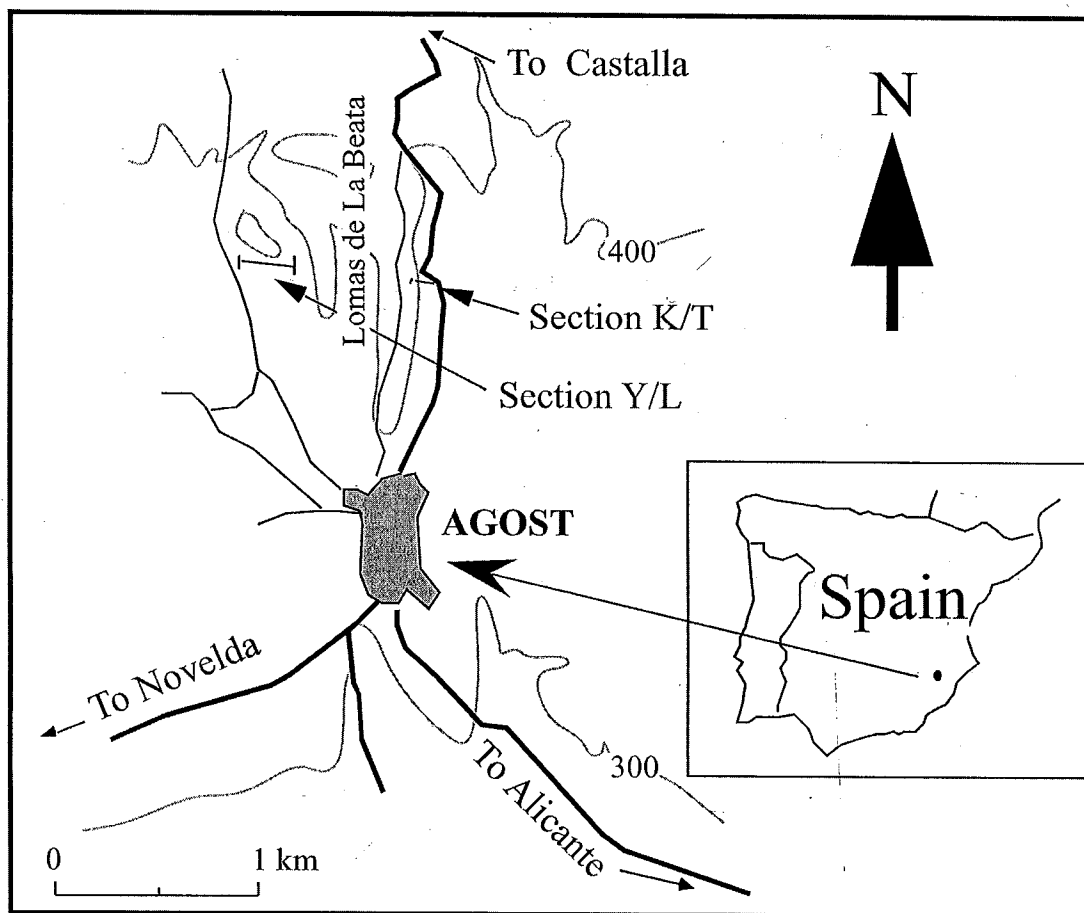


Figure 1. Geographical location of the Agost K/T and Y/L sections.

Agost is about 100 km to the east of the well-known Caravaca section; both sections have a similar lithology of gray marls and calcareous marls, and have been considered as some of the most continuous land-based K/T sections. The Agost section was first described by Leclerc (1971), who documented the planktic foraminiferal faunas and argued that the sedimentation was essentially continuous from the Santonian to the Eocene. Since then, the Agost section has been studied by numerous authors (e.g., von Hillebrandt, 1974; Groot *et al.*, 1989; Smit, 1990; Canudo *et*

al., 1991; Molina *et al.*, 1996; Pardo *et al.*, 1996; Arenillas, 2000; Arz, 2000; Alegret, 2002) who analysed the micropaleontology, biostratigraphy and magnetostratigraphy.

The Upper Cretaceous and Lower Tertiary sediments at Agost are included into the upper part of the Quipar-Jorquera Formation, originally described by Van Veen (1969). According to Vera (1983), this formation is Cenomanian to Eocene in age, and shows similar characteristics across the Inner Prebetic. The Maastrichtian sediments consist of pelagic gray massive marls with interbedded calcareous marls; the latter are rare or absent in the uppermost Maastrichtian. These marly sediments are rich in foraminifera, ostracods and other microfossils (Usera *et al.* 2000; Molina *et al.* 2001). The K/T boundary lies within Chron 29R (Groot *et al.*, 1989) and is marked by a sharp contact between the Maastrichtian marls and a 12 cm thick layer of black clays, with a 2-3 mm thick, red ferruginous level at its base. It contains goethite and hematite clasts, green (probably glauconitic) clasts, and scarce foraminifers, and it is enriched in Ir, Ni-rich spinels, Co, Cr and sanidine spherules (interpreted as altered microtektites). This oxidized, Fe-rich level has been called "fall-out layer", and it marks the K/T boundary (Smit, 1982, 1990; Canudo *et al.*, 1991; Arz *et al.*, 1992; Martínez Ruiz *et al.*, 1992, 1999; Molina *et al.*, 1996; Alegret *et al.*, 2003).

The Maastrichtian sediments consist of pelagic gray massive marls with interbedded calcareous marls; the latter are rare or absent in the uppermost Maastrichtian. The Danian sediments consist of the dark clay level at the base, which is overlain by a 10 cm thick layer of massive gray clays and two decimeter-thick, tabular bodies of marly limestones, with a decimeter-thick intercalated layer of calcareous marls. The remainder of the studied Danian section consists of massive gray marls, including a 10 cm-thick body of marly limestones located 230 cm above the K/T boundary. Trace fossils are frequent across the K/T boundary. Ichnological approach was performed by analyzing ichnotaxa, relative abundance, horizontal and vertical distribution of trace fossils, and cross-cutting relationship (Rodríguez-Tovar in Molina *et al.*, 2001).

MAGNETOSTRATIGRAPHY

A detailed magnetostratigraphic analysis of the Agost section, including the K/T boundary, was reported by Groot *et al.* (1989). Thermal demagnetization, contrary to alternating field demagnetization, succeeds in revealing the polarity of the characteristic remanent magnetization, although an overlap in blocking temperature spectrum exists with a normal polarity, secondary magnetization component. The K/T boundary occurs at two-thirds from the base of a reversed polarity zone; the comparison with earlier results at Gubbio suggests that this polarity zone can be correlated to chron C29r.

MINERALOGY AND GEOCHEMISTRY

According to Martínez-Ruiz *et al.* in Molina *et al.* (2001), the K/T boundary layer is characterized by a sharp decrease in carbonate content and a subsequent increase in the proportion of clays. Smectite is the main component of the boundary layer as well as diagenetically altered spherules made up of either potassium feldspar or iron oxides (Smit, 1990; Martínez-Ruiz *et al.*, 1992, 1997; Ortega-Huertas *et al.*, 1995, 1998). Other trace minerals such as celestine, barite, rutile, Cr oxides, chlorite and palygorskite are also observed in the boundary layer and in the dark marly clays deposited above this layer.

The K/T boundary at Agost is marked by significant geochemical anomalies. The boundary is characterized by a large increase of Ir and other PGEs. The boundary is also marked by high contents of different chemical elements such as Fe, Cr, Co, Ni, Cu, Zn, As or Sb and significant changes in $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ (Smit, 1990, Martínez-Ruiz *et al.*,

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1992, 1994, 1999). The geochemical composition of the boundary layer at Agost and the enrichment in typical extraterrestrial elements support the impact scenario at the end of the Cretaceous.

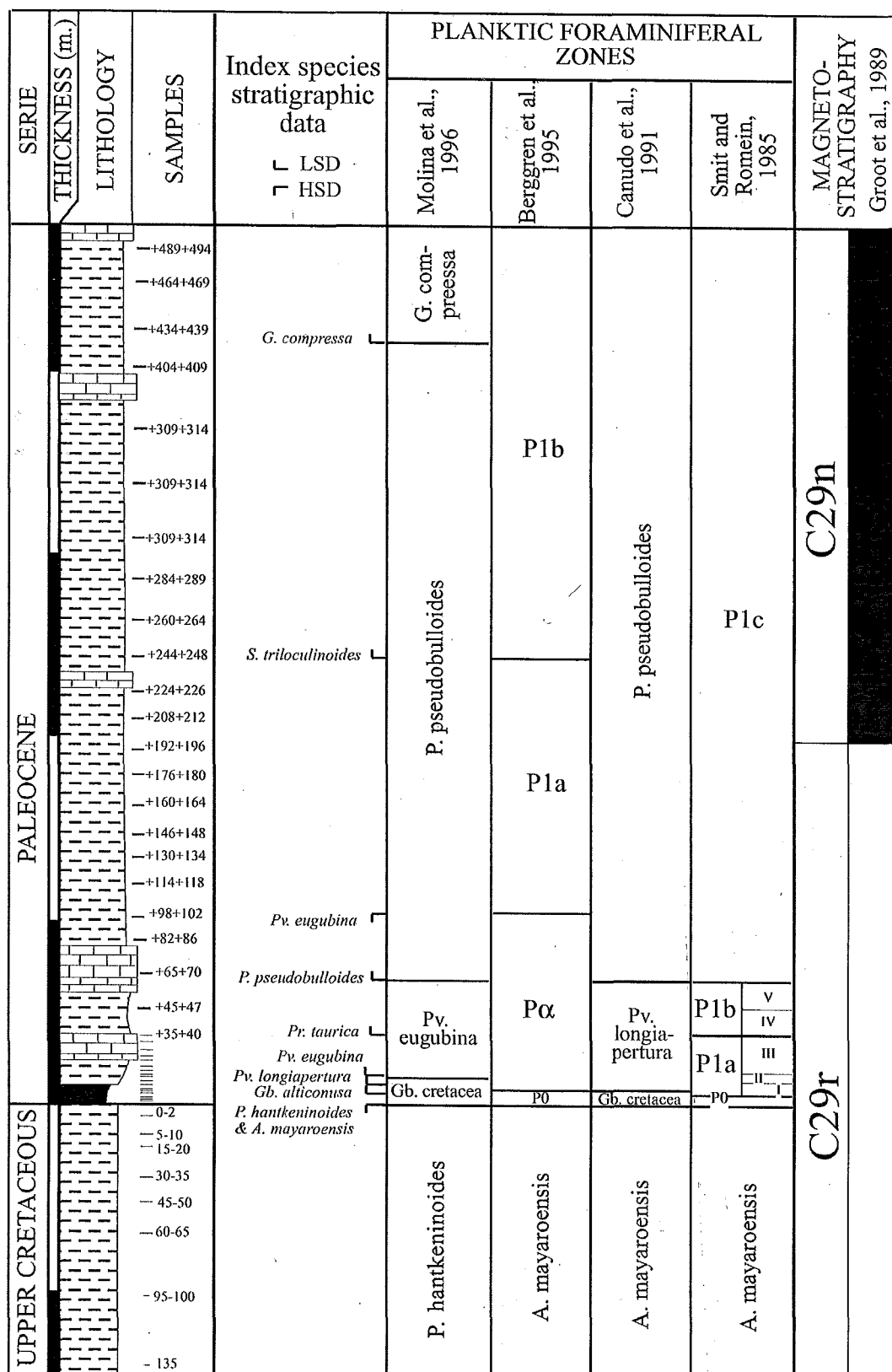


Figure 2. Magnetostratigraphy and planktic foraminiferal biostratigraphy at Agost.

PLANKTIC FORAMINIFERA

Biostratigraphy

The Agost planktic foraminiferal biostratigraphy was studied by Molina *et al.* (1996) who documented that the stratigraphic ranges are very similar to those of the Caravaca section in Spain and the well known El Kef section in Tunisia. Molina *et al.* (1996) used the classical system of biozonation, identifying six biozones across the K/T boundary at Agost: *Abathomphalus mayaroensis* Biozone, *Plummerita hantkeninoides* Biozone, *Guembelitra cretacea* Biozone, *Parvularugoglobigerina eugubina* Biozone, *Parasubbotina pseudobulloides* Biozone and *Globanomalina compressa* Biozone. These biozones were defined as follows:

Abathomphalus mayaroensis Biozone: Biostratigraphical interval between the lowest stratigraphic datum (LSD) of *Abathomphalus mayaroensis* and the LSD of *Plummerita hantkeninoides*.

The characteristic planktic foraminiferal species in this biozone are *Heterohelix planata*, *H. navarroensis*, *H. globulosa*, *H. glabrans*, *H. pulchra*, *H. labellosa*, *H. postsemicostata*, *H. punctulata*, *Pseudotextularia nuttalli*, *P. elegans*, *P. intermedia*, *Gublerina acuta*, *G. cuvillieri*, *Pseudoguembelina costulata*, *P. kempensis*, *P. palpebra*, *P. excolata*, *P. hariaensis*, *P. costellifera*, *Planoglobulina acervulinoides*, *P. carseyae*, *P. multicamerata*, *P. manuelensis*, *Racemiguembelina powelli*, *R. fructicosa*, *Guembelitra cretacea*, *G. trifolia*, *Hedbergella monmouthensis*, *H. holmdelensis*, *Globigerinelloides rosebudensis*, *G. yaucoensis*, *G. subcarinatus*, *G. volutus*, *G. prairiehillensis*, *Schackoina multispinata*, *Globotruncanella caravacaensis*, *G. petaloidea*, *G. pschadae*, *G. minuta*, *G. havanensis*, *Archaeoglobigerina cretacea*, *A. blowi*, *Rugoglobigerina rugosa*, *R. hexacamerata*, *R. pennyi*, *R. scotti*, *R. macrocephala*, *R. rotundata*, *R. milamensis*, *R. reicheli*, *Globotruncana arca*, *G. aegyptiaca*, *G. rosetta*, *G. mariei*, *Globotruncanita stuarti*, *G. stuartiformis*, *G. angulata*, *G. insignis*, *G. fareedi*, *G. conica*, *G. dupeblei*, *G. falsocalcarata*, *Contusotruncana contusa*, *C. patelliformis*, *C. plicata*, *C. walfischensis*, *Gansserina gansseri*, *G. wiedenmayeri*, *Abathomphalus intermedius* and *A. mayaroensis*.

Plummerita hantkeninoides Biozone: Biostratigraphical interval characterized by the total range of the nominate taxon, *Plummerita hantkeninoides*. At the Agost section, the total range of *P. hantkeninoides* spans the top 3.45 m of the Maastrichtian.

The characteristic planktic foraminiferal species in this biozone are *Plummerita hantkeninoides*, *Heterohelix planata*, *H. navarroensis*, *H. globulosa*, *H. glabrans*, *H. pulchra*, *H. labellosa*, *H. postsemicostata*, *H. punctulata*, *Pseudotextularia nuttalli*, *P. elegans*, *P. intermedia*, *Gublerina acuta*, *G. cuvillieri*, *Pseudoguembelina costulata*, *P. kempensis*, *P. palpebra*, *P. excolata*, *P. hariaensis*, *P. costellifera*, *Planoglobulina acervulinoides*, *P. carseyae*, *P. multicamerata*, *P. manuelensis*, *Racemiguembelina powelli*, *R. fructicosa*, *Guembelitra cretacea*, *G. trifolia*, *Hedbergella monmouthensis*, *H. holmdelensis*, *Globigerinelloides rosebudensis*, *G. yaucoensis*, *G. subcarinatus*, *G. volutus*, *G. prairiehillensis*, *Schackoina multispinata*, *Globotruncanella caravacaensis*, *G. petaloidea*, *G. pschadae*, *G. minuta*, *G. havanensis*, *Archaeoglobigerina cretacea*, *A. blowi*, *Rugoglobigerina rugosa*, *R. hexacamerata*, *R. pennyi*, *R. scotti*, *R. macrocephala*, *R. rotundata*, *R. milamensis*, *R. reicheli*, *Globotruncana arca*, *G. aegyptiaca*, *G. rosetta*, *G. mariei*, *Globotruncanita stuarti*, *G. stuartiformis*, *G. angulata*, *G. insignis*, *G. fareedi*, *G. conica*, *G. dupeblei*, *G. falsocalcarata*, *Contusotruncana contusa*, *C. patelliformis*, *C. walfischensis*, *Abathomphalus intermedius* and *A. mayaroensis*.

Guembelitra cretacea Biozone: Biostratigraphical interval between the highest stratigraphic datum (HSD) of *Plummerita hanikeninoides*, precisely at the K/T boundary, and the LSD of *Parvularugoglobigerina eugubina*. The *G. cretacea* Biozone spans 14 cm at Agost and is mainly characterised by black clays that contain a well preserved autochthonous fauna. The first Tertiary planktic foraminifera occurs in the lower part of this biozone.

In the lower part of this biozone, in the stratigraphical interval equivalent to the Zone P0 of Berggren *et al.* (1995), the characteristic planktic foraminiferal species are *Guembelitra cretacea*, *Gb. cf. trifolia*, *Hedbergella monmouthensis*, *H. holmdelensis* and *Heterohelix globulosa* and *H. navarroensis*, being the dominant species *Gb. cretacea* and *Gb. cf. trifolia* (acme of *Guembelitra*).

In the upper part of the biozone, the characteristic planktic foraminiferal species are *Parvularugoglobigerina longiapertura*, *Pv. umbrica*, *Pv. perexigua*, *Globoconusa? alticonusa*, *Gc.? fodina*, *Gc.? cf. fringa*, *Woodringina claytonensis*, *Guembelitra cretacea*, *Gb. cf. trifolia*, *Gb. danica*, *Gb. irregularis* and *Gb.? alabamensis*, being the dominant species *Gb. cretacea*, *Gb. cf. trifolia*, *Pv. longiapertura*, *Pv. umbrica*, *Gc.? alticonusa* and *Gc.? fodina*.

Parvularugoglobigerina eugubina Biozone: Biostratigraphical interval between the LSD of *Parvularugoglobigerina eugubina* and the LSD of *Parasubbotina pseudobulloides*. The *P. eugubina* Biozone is 45 cm-thick at Agost.

In the lower part of this biozone, the characteristic planktic foraminiferal species are *Parvularugoglobigerina eugubina*, *Pv. sabina*, *Pv. perexigua*, *Pv. longiapertura*, *Pv. cf. hemisphaerica*, *Globoconusa? alticonusa*, *Gc.? fodina*, *Gc.? cf. fringa*, *Gc.? minutula*, *Gc.? extensa*, *Woodringina claytonensis*, *W. hornerstownensis*, *Chiloguembelina morsei*, *Ch. midwayensis*, *Guembelitra cretacea*, *Gb. cf. trifolia*, *Gb. danica*, *Gb. irregularis* and *Gb.? alabamensis*, being the dominant species *Pv. eugubina*, *Pv. sabina*, *Pv. longiapertura*, *Pv. perexigua*, *Gc.? fodina* and *Gc.? cf. fringa*.

In the upper part of the biozone, the characteristic planktic foraminiferal species are *Parvularugoglobigerina eugubina*, *Pv. sabina*, *Pv. cf. hemisphaerica*, *Globanomalina archeocompressa*, *G. imitata*, *Globoconusa? alticonusa*, *Gc.? minutula*, *Gc.? extensa*, *Eoglobigerina simplicissima*, *E. eobulloides*, *E. praeedita*, *P. moskvini*, *Woodringina claytonensis*, *W. hornerstownensis*, *Chiloguembelina morsei*, *Ch. midwayensis*, *Guembelitra cretacea*, *Gb. cf. trifolia*, *Gb. danica*, *Gb. irregularis* and *Gb.? alabamensis*, being the dominant species are *Pv. eugubina*, *Pv. sabina*, *Gc.? cf. fringa*, *Gc.? fodina*, *W. hornerstownensis* and *Ch. morsei*.

Parasubbotina pseudobulloides Biozone: Biostratigraphical interval between the LSD of *Ps. pseudobulloides* and LSD of *Globanomalina compressa*. At Agost, this biozone spans 3.70 m.

In the lower part of this biozone, the characteristic planktic foraminiferal species are *Globanomalina archeocompressa*, *G. imitata*, *G. planocompressa*, *Eoglobigerina simplicissima*, *E. eobulloides*, *E. praeedita*, *E. trivialis*, *E. microcellulosa*, *E. fringa*, *Parasubbotina moskvini*, *P. pseudobulloides*, *Praemurica taurica*, *Pr. pseudoincontans*, *Woodringina claytonensis*, *W. hornerstownensis*, *Chiloguembelina morsei*, *Ch. midwayensis*, *Guembelitra cretacea*, *Gb. cf. trifolia*, *Gb. danica*, *Gb. irregularis* and *Gb.? alabamensis*, being the dominant species *W. hornerstownensis* and *Ch. morsei*.

In the upper part of the biozone, the characteristic planktic foraminiferal species are *Globanomalina archeocompressa*, *G. imitata*, *G. planocompressa*, *Eoglobigerina simplicissima*, *E. eobulloides*, *E. praeedita*, *E. edita*, *E. pentagona*, *E. trivialis*, *E. tetragona*, *E. microcellulosa*, *E. fringa*, *Subbotina triloculinoides*, *Parasubbotina moskvini*, *P. pseudobulloides*, *P. varianta*, *Praemurica taurica*, *Pr. pseudoincontans*, *Pr. inconstans*, *Woodringina*

claytonensis, *W. hornerstownensis*, *Chiloguembelina morsei*, *Ch. midwayensis*, *Guembelitra cretacea*, *Gb. cf. trifolia* and *Gb. irregularis*, being the dominant species *W. hornerstownensis* and *Ch. morsei*.

Globanomalina compressa Biozone: Biostratigraphical interval between the LSD of *Globanomalina compressa* and the LSD of *Acarinina trinidadensis*. At Agost, this biozone spans 6 m.

The characteristic planktic foraminiferal species in this biozone are *Guembelitra cretacea*, *Woodringina hornerstownensis*, *Chiloguembelina morsei*, *Ch. midwayensis*, *Eoglobigerina praeedita*, *E. simplicissima*, *E. microcellulosa*, *E. eobulloides*, *E. fringa*, *E. edita*, *E. trivialis*, *Parasubbotina moskvini*, *P. pseudobulloides*, *P. varianta*, *Praemruica taurica*, *Pr. inconstans*, *Pr. pseudoinconstans*, *Globanomalina compressa*, *G. planocompressa* and *Globoconusa daubjergensis*.

Planktic foraminifera turnover at Agost

The proposal of a model explaining the planktic foraminiferal mass extinction at the K/T boundary has generated an interesting controversy, and the Agost section has been very relevant to solve it. The origin of this controversy can be found in the Snowbird I Conference in 1980, where Jan Smit presented his data showing that all but one Cretaceous species suddenly became extinct at the K/T boundary, which he interpreted as the result of a large meteorite impact (Smit and Hertogen, 1980; Smit, 1982). These data were questioned by Gerta Keller, who apparently provided evidence that species extinctions extended across the K/T boundary with about 1/3 of the species surviving well into the Tertiary (Keller, 1988, 1989a,b). Most recent studies (Molina *et al.*, 1998; Arz *et al.*, 1999; Arenillas *et al.*, 2000 a,b, among others) demonstrated that the pattern of extinction is sudden and catastrophic, being very probably the result of a large meteorite impact as was proposed by Smit and Hertogen (1980) and Alvarez *et al.* (1980).

In order to elucidate this controversy, Molina *et al.* (1996) studied the Agost section, which is very expanded and continuous, and well exposed across the K/T boundary. A total of 68 samples were collected at cm-intervals across the critical K/T boundary interval and at m-intervals below and above the boundary. Planktic foraminifera are well preserved, the assemblages are rich and diverse, and there is almost no evidence of reworking. Thus, this excellent K/T boundary section provided a good opportunity to test the extinction model of Cretaceous species and the evolution of Tertiary species.

Late Maastrichtian assemblages from the Agost section are largely dominated by biserial species (heterohelicids). Planispiral (globigerinelloids) and trochospiral (hedbergellids, rugoglobigerinids and globotruncanids) species are frequent, and triserial species (guembelitriids) and tubulospinose species (schackoinids) are rare. The stratigraphic ranges of these taxa during the late Maastrichtian indicate very few changes in the faunal assemblages, and most of the species are present in the *A. mayaroensis* and *P. hantkeninoides* Biozones. The HSDs of some species such as *Gansserina wiedenmayeri*, *Gansserina gansseri* and *Contusotruncana plicata* occur at the base of the upper Maastrichtian, in the *A. mayaroensis* Biozone. The HSDs of the rest of the species (*Rugoglobigerina milamensis*, *Archaeoglobigerina cretacea*, *Gublerina acuta* and *Rugoglobigerina pennyi*) occur in the upper part of the *P. hantkeninoides* Biozone (Fig. 2). Only one species (*P. hantkeninoides*) has its LSD in this interval. Quantitative planktic foraminiferal analysis of the uppermost 2.25 m of the Cretaceous shows little variation among the relative abundances of the different species (Fig. 3 in Molina *et al.*, 1996).

A total of 47 species have their last record in coincidence with the yellow-red layer that marks the K/T boundary. We double-checked this coincidence by scanning the residue of the uppermost Cretaceous samples. This

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methodology is necessary in order to minimize the Signor-Lipps (1982) effect, because certain rare species could appear to become extinct before their real moment of extinction (Canudo *et al.* 1991). The total percentage of the species that became extinct in coincidence with the K/T boundary is about 70% of the species, which clearly implies the most important extinction event in the history of planktic foraminifera. Most of these taxa are large, complex forms adapted to deep environments. In contrast, the small, cosmopolitan forms that were largely surface dwellers were more abundant (e.g., *Heterohelix globulosa* and *Heterohelix navarroensis*).

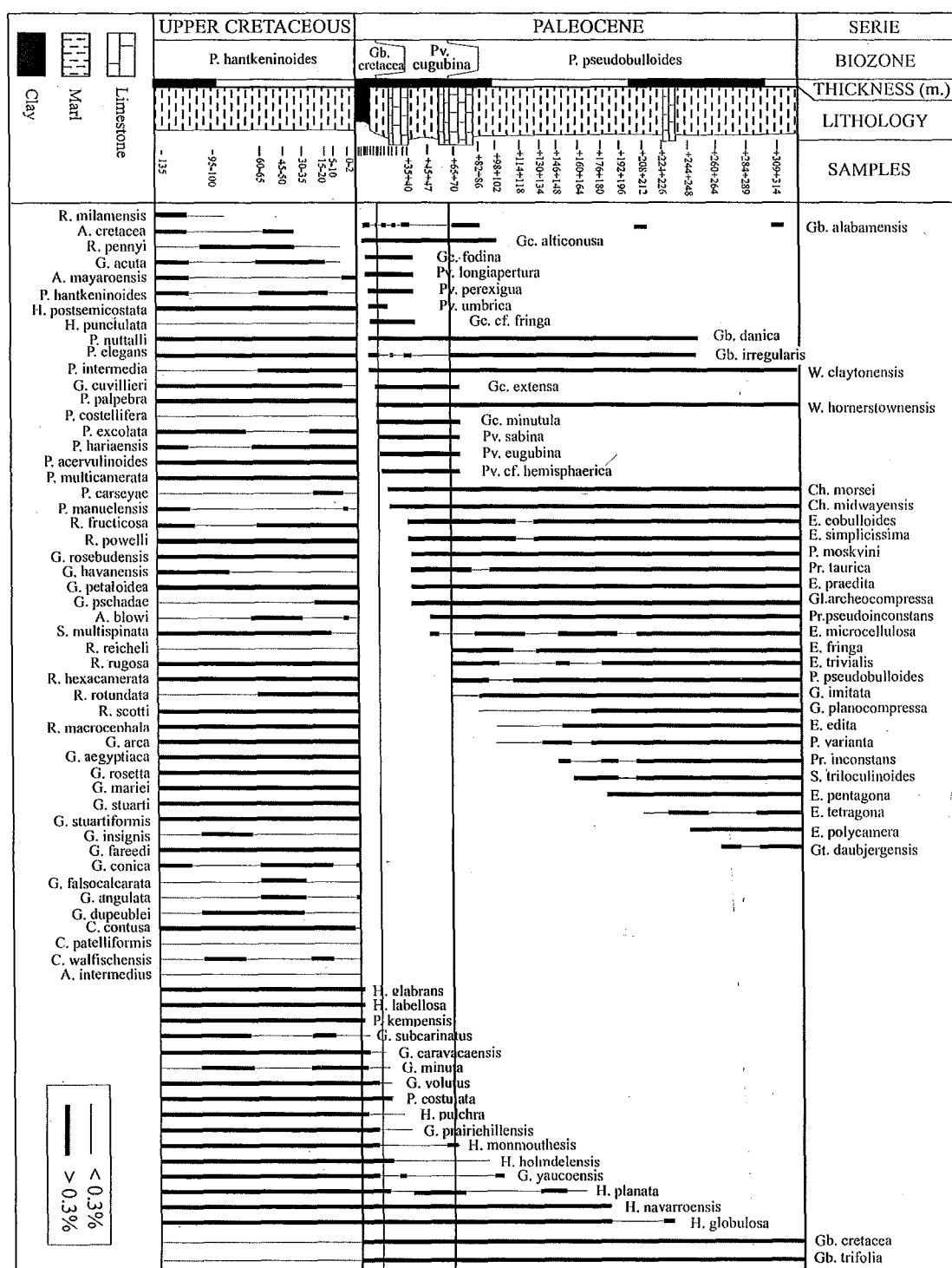


Figure 3. Planktic foraminiferal ranges across the Cretaceous/Tertiary boundary at Agost.

In order to eliminate the potential problem of reworking in a high resolution sampling, Molina *et al.* (1996) ignored the presence of isolated specimens in a sample or those with a different preservation, assuming that they are reworked and hence did not list them in their data tables or figures. In the lowermost Tertiary (*G. cretacea*, *P. eugubina*, *P. pseudobulloides* and the lower part of *G. compressa* Biozones), Molina *et al.* (1996) identified a total of 14 Cretaceous species that can be considered possible Cretaceous survivors or reworked. These species are cosmopolitan, small and simple surface dwellers that disappeared during the lowermost Danian (Fig. 3).

The guembelitrids (*Guembelitra trifolia* and *G. cretacea*) are rare in the Upper Cretaceous, but these opportunistic species are abundant in the lowermost Tertiary, just after the main planktic foraminiferal extinction event. The rest of the small Cretaceous possible survivors are less abundant in the Danian than in the Maastrichtian, indicating the possibility of reworking.

In the lowermost Danian new opportunistic cosmopolitan species evolved. Two main Danian assemblages are recognised. The first assemblage to appear consists of the small cosmopolitan surface dwellers, which originated in the *G. cretacea* Biozone and became extinct in the lower part of the *Ps. pseudobulloides* Biozone. The second assemblage originated in the *Pv. eugubina* Biozone and diversified within the lower part of the *Ps. pseudobulloides* Biozone, where these taxa reached normal size.

The relative abundance of species that evolved after the K/T boundary are dominant during the early Danian and most of them became extinct near the base of the *P. pseudobulloides* Biochron (e.g., *Parvularugoglobigerina longiapertura*, *Pv. eugubina*, *Pv. sabina*, *Globoconusa fodina* and *G. alticonusa*). After the disappearance of these species, the dominant species were *Woodringina claytonensis*, *Woodringina hornerstownensis* (= *Chiloguembelina morsei*), *Chiloguembelina taurica* and *Chiloguembelina midwayensis* (Fig. 3).

In conclusion, the catastrophic mass extinction of about 70% of the species of planktic foraminifera exactly coincides with the base of the yellow-red layer containing the impact evidence in Spanish, Tunisian, and other sections (Molina *et al.*, 1998; Arenillas *et al.*, 2000b). For these reasons, we suggest that the pattern of extinction and origination is very plausible with the impact theory, which caused the extinction of about 90% of the species of planktic foraminifera across the K-T transition.

BENTHIC FORAMINIFERA

Although benthic foraminifera are considered as excellent proxies for paleodepth, ocean productivity and oxygenation, there have been considerably fewer studies of benthic than of planktic foraminifera, and few data are available on upper Maastrichtian through lower Danian benthic foraminifera from Southeastern Spain. The benthic foraminiferal faunas at Caravaca were first briefly described by Smit (1990), later included in an overview by Keller (1992), and finally described by Coccioni *et al.* (1993), Coccioni and Galeotti (1994) and Widmark and Speijer (1997a, b).

Benthic foraminifera from the Upper Cretaceous and Lower Paleogene at Agost were included in the study by Pardo *et al.* (1996), who observed a lack of severe extinctions and suggested that climatic changes and variations in sea level explain the observed faunal changes. More recently, Alegret *et al.* (2003) described the benthic foraminiferal turnover across the K-T transition, and inferred paleoenvironmental and paleobathymetrical changes at Agost; the main results obtained by these authors are briefly commented below:

Paleobathymetry

Benthic foraminiferal distribution is determined by several depth-related parameters, and this group is thus an excellent tool to infer the paleobathymetry. The paleodepths indicated by the benthic foraminiferal faunas are clearly of great importance to interpret the environment of deposition of the K/T sediments.

Pardo *et al.* (1996) explained the faunal turnover of Upper Cretaceous and lower Paleogene benthic foraminifera at Agost in terms of climatic changes and variations in sea level. They concluded that paleodepths varied between upper bathyal and outer neritic, similar to depth estimates for nearby Caravaca by Keller (1992). Nevertheless, Alegret *et al.* (2003) recently developed and documented a detailed paleobathymetric reconstruction of the Upper Cretaceous and Lower Paleogene sediments at Agost; according to these authors, benthic foraminifera indicate an

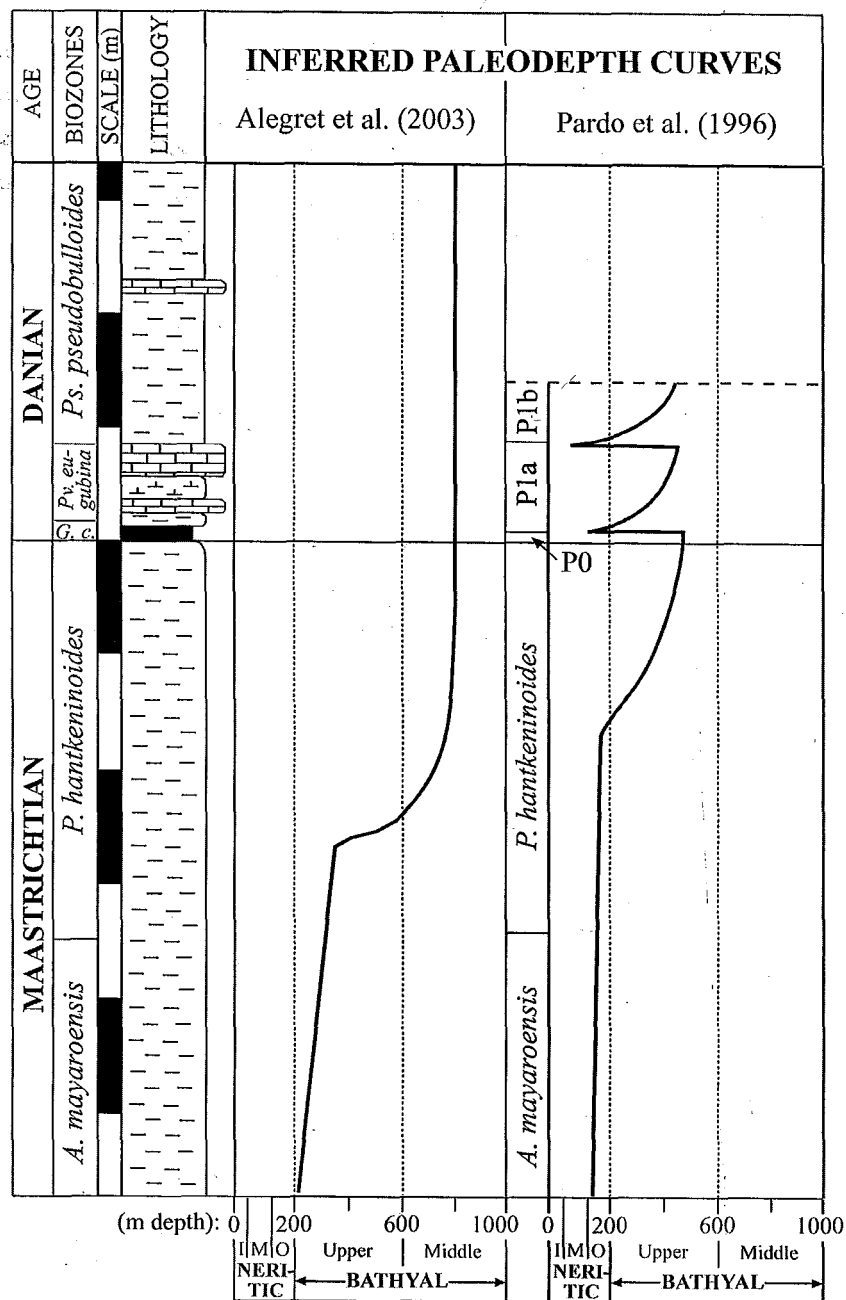


Figure 4. Comparison between paleodepth curves inferred by Alegret *et al.* (2003) and Pardo *et al.* (1996).
I = Inner neritic; M = Middle neritic; O = Outer neritic. Modified from Alegret *et al.* (2003).

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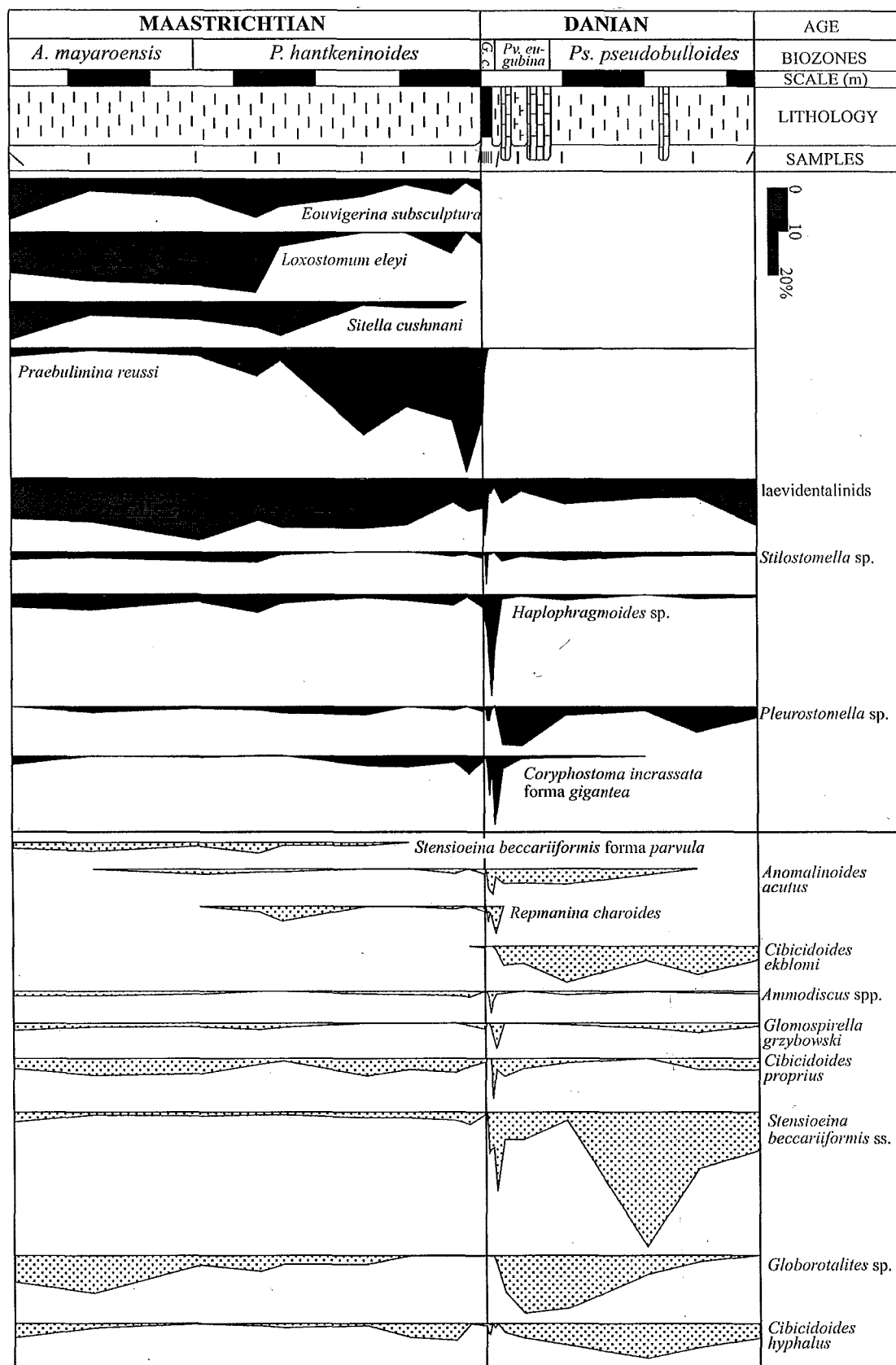


Figure 5. Relative abundance of the most representative infaunal (black) and epifaunal (dotted areas) benthic foraminiferal species at Agost. *G. c.* = *G. cretacea* Biozone.

uppermost bathyal depth of deposition during the *A. mayaroensis* and lower part of the *P. hantkeninoides* Biochrons (Fig. 4). Paleodepths increased to middle bathyal about 2.4 m (~120-150 kyr) below the K/T boundary, and remained unchanged through the rest of the section (through the *Ps. pseudobulloides* Biochron).

A comparison between paleodepth assignments proposed by Pardo *et al.* (1996) and Alegret *et al.* (2003) is shown in Fig. 4. According to the later ones, differences between these paleodepth curves may be due to the fact that Pardo *et al.* (1996) misidentified several benthic foraminiferal species, such as *Praebulimina carseyae*-*P. reussi* or *Stensioeina beccariiiformis* ss.-*S. beccariiiformis* forma *parvula*, and also because they assigned upper depth limits to taxa without consideration of the depths at which these taxa are usually observed, or are common.

Benthic foraminiferal turnover at Agost and paleoenvironmental inferences

The K/T boundary marks one of the largest mass extinctions of the Phanerozoic but survival rates of different groups of marine organisms varied with habitat (Peryt *et al.*, 2002). Planktic foraminifera suffered a catastrophic mass extinction (e.g., Arenillas *et al.*, 2000 a,b), whereas the extinction rate within benthic foraminiferal assemblages decreased with increasing depths of the basin (e.g., Thomas, 1990). Benthic assemblages, however, exhibit various degrees of faunal restructuring even in the absence of major extinction (e.g., Alegret *et al.*, 2003).

Upper Maastrichtian benthic foraminiferal assemblages are dominated by calcareous foraminifers (~80%) with tapered tests, such as *Loxostomum eleyi*, laevidentalinids and *Eouvigerina subsculptura*. The upper half of the *P. hantkeninoides* Biozone is dominated by different tapered species such as *Praebulimina reussi*, *Spiroplectamina spectabilis* and laevidentalinids (Fig. 5). These Upper Cretaceous faunas were interpreted by Alegret *et al.* (2003) as being dominated by infaunal morphogroups, suggesting a moderately eutrophic environment.

Only 5% of the species (e.g., *Bolivinoidea draco*) became extinct globally at the end of the Cretaceous, but a temporary faunal turnover started at the K/P boundary. Absolute abundances of benthic foraminifera are low in the lowermost 10 cm of the black-clay layer at Agost, and dissolution may have affected the faunas, leading to relatively high abundances of agglutinated taxa. The Danian assemblages were dominated by epifaunal (*Stensioeina beccariiiformis*, *Globorotalites* spp., *Cibicidoides hyphalus*, *Cibicidoides ekblomi*; Fig. 5) or mixed epifaunal-infaunal morphogroups, and suggest that the food supply to the benthos drastically decreased in coincidence with the K/P boundary (Alegret *et al.*, 2003). Furthermore, these authors identified in the lowermost Danian black clay interval several peaks in relative abundance of some taxa (e.g., *Ammodiscus* spp., *Glomospirella grzybowskii*, *Repmanina charoides*, and especially *Haplophragmoides* sp.; Fig. 5) that they consider to be opportunistic species, indicators of an interval during which an overall decrease in productivity was combined with environmental instability.

Alegret *et al.* (2003) speculate that the strong variability in the fauna during the first 10-15 kyr of the Danian reflects not just a collapse of the food supply, but also a major change in the composition of the food supply as a result of the mass extinction of phytoplankton, as well as a rapidly changing food supply driven by blooms. After stabilization of the ecosystems in surface waters (at the end of the *G. cretacea* Biochron), the high abundance of epifaunal morphogroups suggests that productivity did not recover to pre-extinction levels at Agost, at least, ~200 kyr after the K/P boundary.

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