

Agglutinated foraminifers and their response to the Cretaceous/Paleogene (K/P) boundary event at Ain Settara, Tunisia

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ABSTRACT

The outer shelf-upper bathyal section across the Cretaceous/Paleogene (K/P) boundary at Ain Settara (Central Tunisia) has been studied for quantitative changes in agglutinated benthic foraminifers. The studied interval extends from 2.5 m below to 9.6 m above the K/P boundary. Agglutinated foraminifers are a minor component of benthic foraminiferal assemblages and form up to 26% of the assemblages in the studied interval. Thirty five agglutinated species are identified and one new species –*Arenoturrisspirillina tunisiana*– is described. The uppermost Maastrichtian benthic foraminiferal assemblages are highly diversified and composed of mixed epifaunal and infaunal morphogroups. Infaunal *Heterostomella*, *Bolivinopsis*, *Clavulinoides*, *Tritaxia* and *Gaudryina* are the most common agglutinated taxa; *Recurvoides* and *Haplophragmoides* are also common.

The dramatic change in the structure of benthic foraminiferal assemblages corresponds to the layer with the impact evidence, i.e., at the base of the *Guembelitra cretacea* Zone, where highly diversified, low-dominance upper Maastrichtian assemblages with infaunal and epifaunal morphotypes were suddenly replaced by taxonomically impoverished assemblages, strongly dominated by epifaunal morphotypes. At this level all agglutinated species with an inferred infaunal mode of life disappeared. Some of them went extinct (e.g. *Heterostomella austinana*, *Bolivinopsis rosula*), whereas others (e.g., *Clavulinoides*, *Gaudryina*, *Tritaxia*) reappeared in the Lower Danian as Lazarus taxa after a shorter or longer period of emigration.

We interpret that a sudden drop in primary productivity and changes in the phytoplankton composition (from calcareous nannoplankton to dinoflagellates) resulted in extinction or temporary emigration of most infaunal morphotypes as well as a temporary disappearance of calcareous-cemented agglutinated foraminifers. The sudden collapse of primary productivity is consistent with an asteroid impact at the K/P boundary.

INTRODUCTION

The K/P boundary stratotype section at El Kef is one of the most well-documented K/P sections, but none of the papers dealing with benthic foraminiferal assemblages from this section (Keller, 1988; Speijer & van der Zwaan, 1994, 1996; Widmark & Speijer, 1997; Coccioni & Galeotti, 1998; Kouwenhoven, 2000) focussed on agglutinated foraminifers. Studies on benthic foraminifers show that they were not so severely affected by the K/P boundary biotic crisis as planktic ones, at least in terms of extinction (e.g., Thomas, 1990; Kaiho, 1992; Widmark & Malmgren, 1992; Kuhnt & Kaminski, 1993; Coccioni & Galeotti, 1994, 1998; Speijer & van der Zwaan, 1994, 1996; Widmark & Speijer, 1997; Peryt *et al.*, 1997, 2002; Kouwenhoven, 2000; Alegret *et al.*, 1999, 2001). Most authors suggest that the causes of extinction and/or restructuring of benthic foraminiferal assemblages across the K/P boundary are indirectly linked with an extraterrestrial asteroid impact, whereas Keller (1988) postulated a major drop in sea level and oxygen content during the earliest Danian to explain the observed change in benthic foraminiferal assemblages in the El Kef section.

The nearby Ain Settara Section offers a good opportunity to study the faunal and palaeoenvironmental turnover at the K/P boundary. The aim of this study is to describe agglutinated foraminiferal species and to trace changes in their relative abundance

within benthic foraminiferal assemblages in the uppermost Maastrichtian and lowermost Danian strata at Ain Settara, Tunisia.

MATERIAL AND METHODS

The Ain Settara section is located in Central Tunisia, in the Kalaat Senan area, about 50 km south of the El Kef K/P boundary stratotype (Fig. 1). The K/P boundary, identified on the basis of general lithological characteristics, species extinction, and the occurrence of cosmic markers, is located within the lower part of the marly El Haria Formation (Robaszynski *et al.*, 2000; Tribouillard *et al.*, 2000; Arenillas *et al.*, 2000; Dupuis *et al.*, 2001). The basal part of the El Haria Formation is composed of about 80-m thick series of dark grey jarositic marls that alternate with 0.2 to 0.8 m thick whitish, more carbonate-rich beds. They are overlain by about 150-m thick series of blue grey marls alternating with whitish limestone beds. At the base of those marls there is a 60-cm thick dark clayey layer that encompasses the K/P boundary. The K/P boundary is recognised here by the presence of an Ir anomaly and a very concentrated horizon of Ni-rich spinels just above the yellowish-red horizon of jarosite and FeO. Arenillas *et al.* (2000) suggested that the layer with geochemical anomalies, which is located 55-cm below the top of the boundary clay at

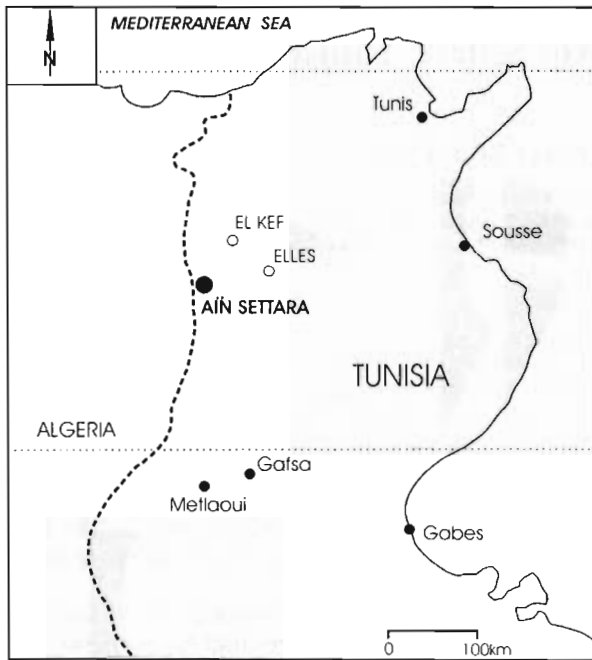


Figure 1. Geographical location of the Ain Settara section in Tunisia

Ain Settara, is very good evidence for the extraterrestrial bolide impact.

A total of 34 samples were analysed micropaleontologically from the section 2.5 m below to 9.6 m above the K/P boundary. The studied interval encompasses the upper part of the *Plummerita hantkeninoides* Zone, *Guembeltria cretacea*, *Parvularugoglobigerina eugubina* and lower part of the *Parasubbotina pseudobulloides* Zones (Fig. 2).

The 0.4-m-thick topmost part of the *Plummerita hantkeninoides* Zone and the entire *Guembeltria cretacea* Zone (0.6-m-thick) were sampled at high resolution - at 10-cm intervals in the lower and the upper part of this interval; in the last 15 cm below the K/P boundary the sampling distance was 3 cm, and in the first 10 cm above the boundary it was as low as 1-2 cm (Fig. 2). All samples were disaggregated in tap water and diluted H_2O_2 , then washed through a 63 μm sieve and dried at 50°C. A split of the $\geq 63 \mu m$ fraction, containing 300 or more specimens, was used for foraminiferal counts.

Benthic foraminifera are abundant and very well preserved in the studied material except for a 5-cm-thick layer of sediment overlying the impact layer where benthic foraminifera are scarce and poorly preserved; moreover, they are not recorded in the impact layer. The relative abundance of agglutinated and calcareous-hyaline forms and agglutinated species within benthic foraminiferal assemblages, of infaunal and epifaunal forms within agglutinated and calcareous hyaline forms, and of infaunal and epifaunal morphogroups within the agglutinated group were calculated. Results are presented in figures 2 to 5.

Benthic foraminifera were identified at the generic level in this study, according to Loeblich & Tappan's (1987) systematics. Allocation of foraminiferal taxa into morphogroups was largely performed following Jones & Charnock (1985), Corliss & Chen (1988) and Nagy *et al.*, (1995).

RESULTS

A. Biostratigraphy and Agglutinated Foraminiferal Assemblages

The biostratigraphy based on planktic foraminifera proposed by Arenillas *et al.* (2000) is applied in this paper. We recognised the *Plummerita hantkeninoides* Zone in the upper Maastrichtian, and the *Guembeltria cretacea*, *Parvularugoglobigerina eugubina* and *Parasubbotina pseudobulloides* Zones in the Lower Danian. More than thirty species of agglutinated foraminifera have been identified in the studied interval (Figs 2, 3).

Plummerita hantkeninoides Zone

The studied interval encompasses the upper 2.5-m-thick part of the *Plummerita hantkeninoides* Zone and consists of bluish grey bioturbated marl with burrows infilled with black clay at the top (Tribovillard *et al.*, 2000; Dupuis *et al.*, 2001). It represents the top of the Ain Settara Marls.

Agglutinated species form 6 to 26% of benthic foraminiferal assemblages in the topmost part of the planktic foraminifer *Plummerita hantkeninoides* Zone. The number of species varies from 8 to 12. *Heterostomella austinana*, *Bolivinosia rosula*, *Tritaxia globulifera*, *Clavulinoides trilatera* and *Gaudryina pyramidata* are the most common agglutinated taxa. *Spiroplectamina* sp., *Martinotiella palaeocenica*, *Caudammina ovula*, *Bathysiphon gerochi*, *Verneuilina* sp. and *Bolivinosia rosula* in the studied interval are recorded only in this zone.

Guembeltria cretacea Zone

The interval is 0.6 m thick and consists of a 5-cm-thick brownish-black clay, grey silt and heterogeneous brownish-black clay overlain by a 55-cm-thick interval of dark clay with jarosite nodules. Within the lower 5-cm-thick layer there is a very thin layer consisting of a few mm-thick, 2-5 cm long, yellowish to orange-coloured platy nodules made up of jarosite, gypsum, and iron oxides, resulting from pyrite oxidation (Tribovillard *et al.*, 2000; Dupuis *et al.*, 2001). The Ir anomaly and a very concentrated horizon of Ni-rich spinels have been detected just above this horizon (Dupuis *et al.*, 2001), corresponding to the K/P boundary.

A dramatic change in the structure of benthic foraminiferal assemblages corresponds to the layer with the impact evidence, i.e., at the base of the *Guembeltria cretacea* Zone. At this level all species of several benthic foraminiferal genera disappeared (Peryt *et al.*, 2002), among them agglutinated *Verneuilina* sp., *Caudammina ovula*, and *Bathysiphon gerochi* (Figs 2, 3). The abundance of benthic foraminifera drastically decreased as well, and they are very scarce in the lowermost 5-cm-thick layer of sediment. Agglutinated foraminifera make up to 15% of the assemblage in this level, but at the top of this short interval they almost completely disappeared (Fig. 3). *Heterostomella austinana* and *Bolivinosia rosula* went extinct, while species of *Gaudryina*, *Tritaxia*, *Clavulinoides* behaved as Lazarus taxa and reappeared higher in the section. However, in this short interval two agglutinated species, *Ammodiscus cretaceus* and *Arenoturrisspirillina tunisiana* n.sp. bloomed opportunistically. They reached peak abundances up to 8% and 5%, respectively.

In the following 40-cm-thick interval agglutinated foraminifera are very rare. Their contribution to the assemblages does not exceed 1.5%. Only single specimens

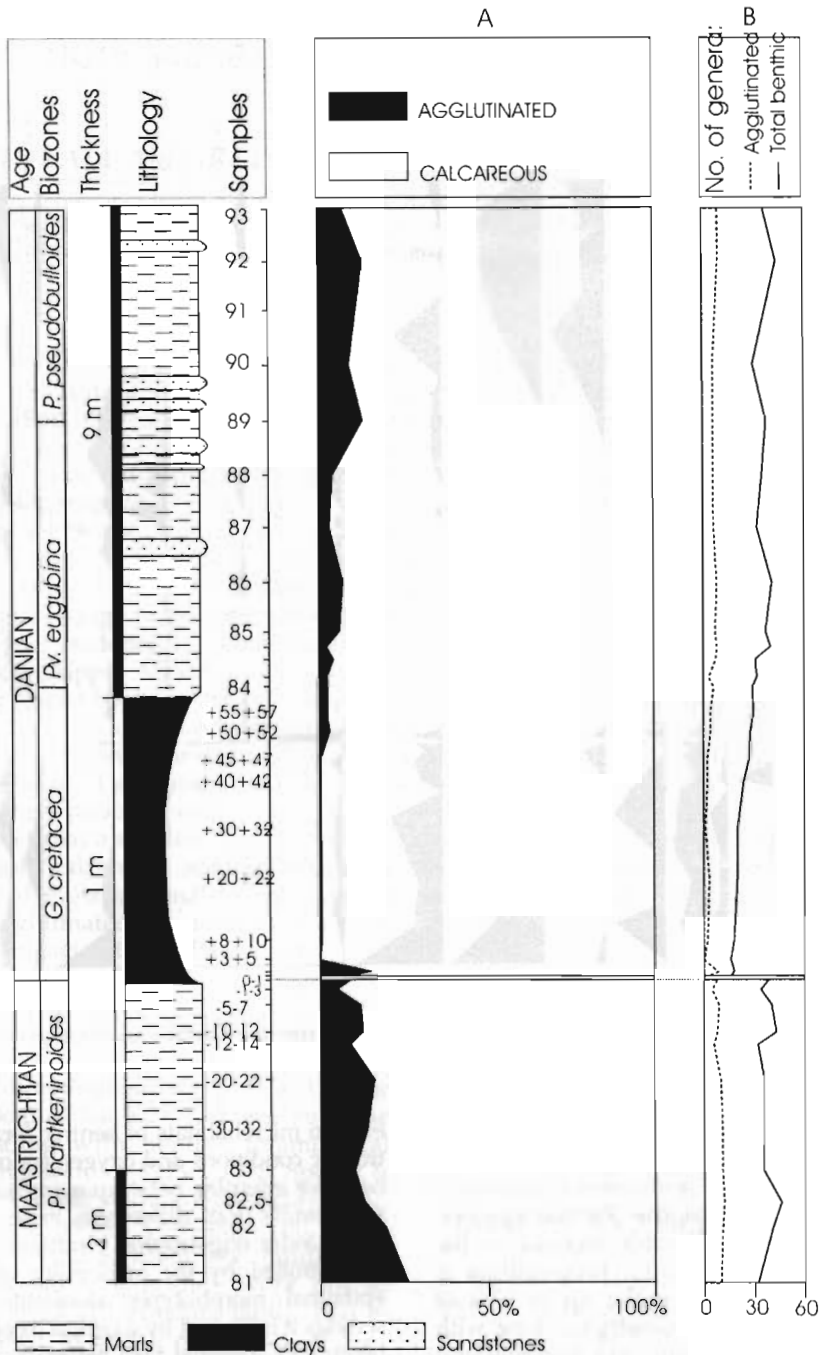


Figure 2. Lithological column and stratigraphy and changes in benthic foraminiferal assemblage composition across the K/P boundary in the Ain Settara section. Biostratigraphy after Arenillas *et al.* (2000). A. relative abundances of calcareous and agglutinated benthic foraminifers within assemblages. B. foraminiferal genus richness.

of *Recurvoides*, *Haplophragmoides*, *Trochammina* and *Marssonella* have been recorded from this interval.

In the topmost 15-cm-thick portion of the *Guembelitra cretacea* Zone agglutinated foraminifers begin very slowly to recover. In this interval their contribution to benthic foraminiferal assemblages increases to 2.5%. Diversity also increases. *Ammodiscus cretaceus*, *Arenoturrispirillina tunisiana* and *Subreophax pseudoscalaria* return from refugia.

***Parvularugoglobigerina eugubina* Zone**

The interval is 4.5-m-thick and consists of light-grey marls intercalated with sandstones (Tribovillard *et al.*,

2000; Arenillas *et al.*, 2000). The process of recovery of agglutinated foraminifers continues gradually up the zone and in the topmost part of this interval they form up to 12% of benthic foraminiferal assemblages. The number of agglutinated species varies from 5 to 9. The taxonomic composition of agglutinated foraminiferal assemblages increases with the return of additional Lazarus species: *Tritaxia globulifera*, *Clavulinoides trilat- era*, *Gaudryina pyramidata*, *G. laevigata*, *G. aisana*. These dominate the agglutinated assemblages in the top- most part of this interval. Several species also appear which are not present in the older sediments: *Ammobaculites* sp., *Vulvulina gracillima*.

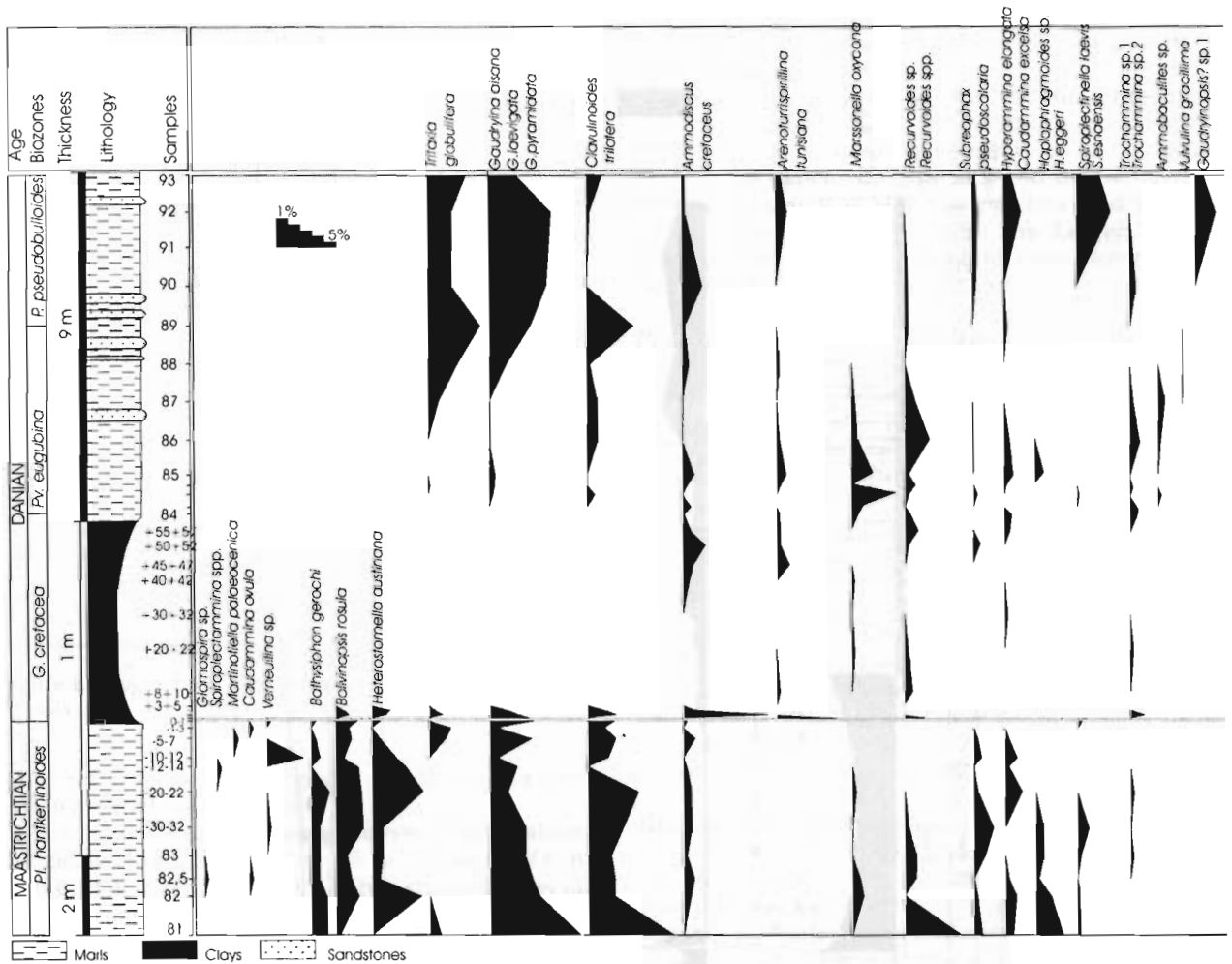


Figure 3. Relative abundances of agglutinated foraminiferal species across the Cretaceous/Paleogene boundary at the Ain Settara section.

Parasubbotina pseudobulloides Zone

The studied part of this zone is 4.5 m thick and consists of intercalated marls and sandstones (Arenillas *et al.*, 2000). When compared to the *Parvularugoglobigerina eugubina* Zone, a considerable increase in the relative abundance of agglutinated foraminifera is observed. In this interval they make up to 17% of assemblages (Figs 2, 3). *Tritaxia*, *Gaudryina* along with *Spiroplectinella* dominate agglutinated foraminiferal assemblages in this interval; *Gaudryinopsis?* sp. 1 appears for the first time.

B. Palaeoecological Response of Agglutinated Foraminifera to the K/P Boundary Event

Benthic foraminifera are sensitive indicators of change in the marine environment. Recent benthic foraminiferal microhabitats are primarily determined by the interplay between the amount of organic matter and oxygen present in the sediment and at the sediment-water interface (Van der Zwaan, 1982; Corliss & Emerson, 1990; Barmavidjaja *et al.*, 1992; Jorissen *et al.*, 1992, 1995). The greatest control comes from the changes in the amount of food available as well as from possible changes in the quality of food (Van der Zwaan, 1982). The ultimate downward organic flux rate controls both the food availability and the oxygen concentrations at the bottom (Barmavidjaja *et al.*, 1992). Jorissen *et al.* (1995)

explain microhabitats of benthic foraminifera in terms of trophic conditions and oxygen concentrations. There is a negative interplay between oxygen and food availability that results from differences in the downward organic flux. Under oligotrophic conditions microhabitat depth is controlled by the availability of food particles and epifaunal morphotypes dominate, but in eutrophic settings it is limited by a critical oxygen level. Infaunal or potentially infaunal taxa generally are more tolerant to low oxygen concentrations and are therefore the first to profit from high food availability. These infaunal groups might survive and even grow in abundance under these environmentally stressed conditions. Infaunal species dominate assemblages associated with relatively high organic carbon values (Corliss & Chen, 1988), and epifaunal ones in more oligotrophic environments (Thomas, 1990; Gooday, 1994; Jorissen *et al.*, 1995).

Environmental requirements of Recent benthic foraminifera have been subject of many studies, and broad classification of sediment type/depth morphotypic associations have been proposed (Corliss, 1985, 1991; Jones & Charnock, 1985; Corliss & Chen, 1988; Kaminski *et al.*, 1988; Kaiho, 1994, 1999; Rathburn & Corliss, 1994; Nagy *et al.*, 1995). Epifaunal mode of life is the most typical for rounded trochospiral, plano-convex trochospiral, milioline and biconvex trochospiral/planispiral morphotypes, while an

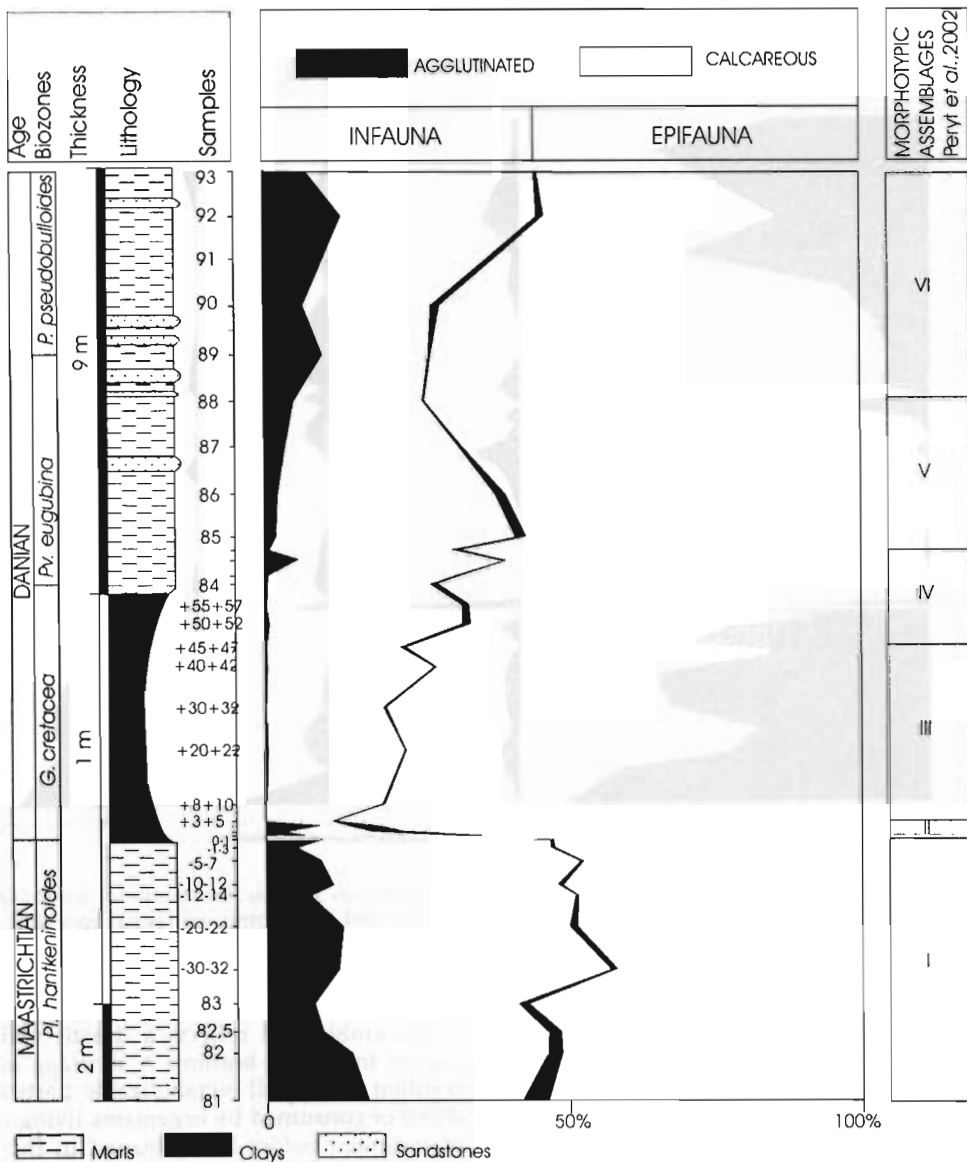


Figure 4. Proportion of agglutinated foraminifers within infaunal and epifaunal morphogroups within benthic foraminiferal assemblages and morphotypic assemblages.

infaunal mode of life prevails within rounded planispiral, flattened ovoid, tapered and cylindrical, spherical, flattened tapered morphotypes.

Morphotype analysis allows us to infer probable microhabitat preferences and environmental parameters such as the food supply to the sea-floor and sea water oxygenation (e.g., Bernard, 1986; Jorissen *et al.*, 1995). One should be careful with these comparisons, however, because the ecology of present-day foraminifera is complex and not fully understood (e.g., Barmavidjaja *et al.*, 1992; Buzas *et al.*, 1993; Linke & Lutze, 1993; Murray, 2001). Peryt *et al.* (2002), assuming that Cretaceous genera were similar in trophic requirements to modern morphologically comparable taxa, recognized in the studied section six assemblages (I-VI) related to changes in the relative abundances of epifaunal and infaunal species. In the present study, we focus on changes in relative abundances of infaunal and epifaunal morphogroups of agglutinated foraminifers within morphotypic assemblages of Peryt *et al.* (2002). Agglutinated foraminifers

do not undergo significant postmortem dissolution and thus they provide a good tool to interpret palaeoecological changes (Murray, 1991; Alve & Murray, 1995; Murray & Alve, 1999).

Assemblage I (uppermost *Plummerita hantkeninoides* Zone -2,4 m-thick interval below the impact layer)

Assemblage I is highly diversified (Peryt *et al.*, 2002; Figs 2, 3) and composed of mixed epifaunal and infaunal morphogroups where epifaunal taxa constitute 43 to 57% of the assemblage (Fig. 4). Within the agglutinated group, which forms 6 to 26% of the assemblage, the morphogroup with inferred infaunal mode of life dominates (Fig. 4). Elongated forms such as *Heterostomella*, *Bolivinospis*, *Clavulinoides* and *Gaudryina* are the most common taxa of this morphogroup; within the epifaunal morphogroup flattened, planispirally enrolled *Ammodiscus* is also common (Figs 3,5). *Spiroplectammina* sp., *Martinotiella palaeocenica*, *Caudammina ovula*, *Bathysiphon gerochi* and *Verneuilina* sp. are recorded in the studied interval only in this assemblage.

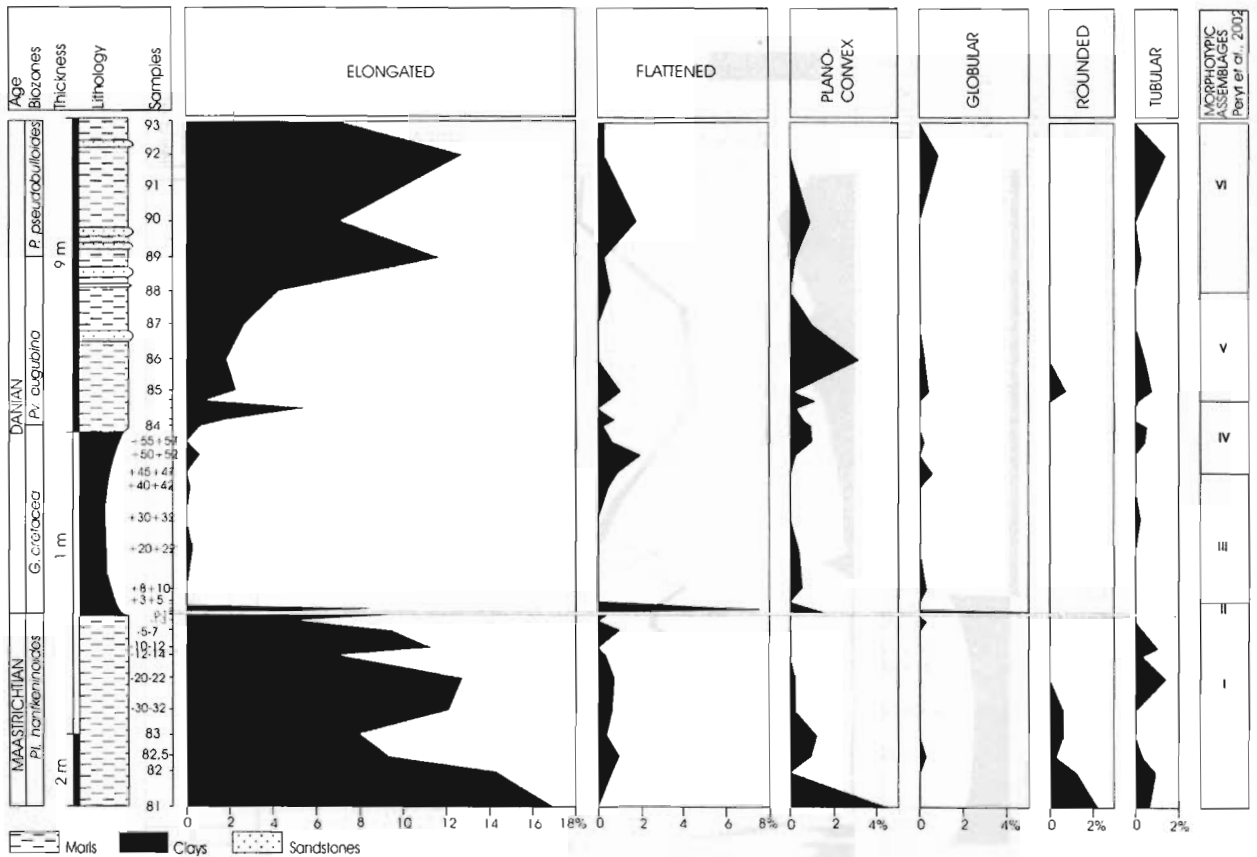


Figure 5. Proportion of agglutinated foraminiferal morphogroups within benthic foraminiferal assemblages (infaunal morphotypes: elongated –cylindrical tapered, flattened tapered, rounded planispiral; epifaunal morphotypes: rounded trochospiral, plano-convex trochospiral, biconvex trochospiral/planispiral, flattened planispiral, tubular) and morphotypic assemblages.

Assemblage I is typical for outer shelf–upper bathyal marine environments with moderate primary productivity and a flux of organic detritus that is sufficient to sustain infaunal bottom-dwellers (Peryt *et al.*, 2002).

Assemblage II (lowermost part of the *Guembelitra cretacea* Zone –5-cm-thick interval directly overlying the impact layer)

In Assemblage II, benthic foraminifers are very scarce and the assemblage is composed almost entirely of epifaunal species. They make up 82 to 90% of the assemblage.

Agglutinated forms contribute to benthic assemblages in a proportion similar to the sediment below the impact layer, i.e., 15%. In this short interval epifaunal flattened planispiral and evolute *Ammodiscus cretaceus* appeared to be very successful, tripling its previous contribution and exceeding 7% of the assemblage. *Arenoturrspirillina tunisiana* n.sp., *Recurvoides* sp. and *Trochammina* sp. are other species with inferred epifaunal mode of life that reappeared in this interval. *Arenoturrspirillina tunisiana* exceeded 5% in the assemblage (figs. 3, 5). Elongated forms common in the Assemblage I such as *Bolivinopsis*, *Heterostomella*, *Tritaxia*, *Gaudryina* and *Clavulinoides* are present in similar proportions as below the impact layer (Figs 3, 5). About 5 cm above the impact layer agglutinated forms suddenly almost completely disappeared (Figs 2, 3, 4, 5).

Assemblage II reflects a drastic collapse in food supply to the sea bottom. A shortage in food supply resulted in that all metabolizable particles were oxidized or consumed by organisms living on the surface of sediment before being buried in the sediment, so that no food remained for infaunal taxa (Peryt *et al.*, 2002).

Assemblage III (lower-middle part of the *Guembelitra cretacea* Zone –an interval from 5 to 45 cm above the impact layer)

Assemblages recorded from the lower and middle part of the *Guembelitra cretacea* Zone are poorly diversified, almost completely devoid of agglutinated foraminifers, and dominated by epifaunal morphogroups, (Peryt *et al.*, 2002; Figs 2, 3, 4, 5). A gradual decrease in contribution of epifaunal forms is observed up in the section – from 92% about 5 cm above the impact layer to 75% forty centimetres higher up the section. Agglutinated foraminifers are represented by single specimens of epifaunal *Recurvoides*, *Hyperammima*, *Trochammina* and infaunal *Marssonella*.

The disappearance of common *Ammodiscus* suggests that food supply to the benthos decreased even more at the beginning of this interval. This assemblage indicates very little food available on the seabottom: an extreme oligotrophic environment (Peryt *et al.*, 2002). *Ammodiscus cretaceus* reappears in the topmost part of this interval.

Assemblage IV (*Parvularugoglobigerina eugubina* Zone –0,9-m-thick interval from 45 cm to 1,35 m above the impact layer)

The trend of decreasing relative abundance of the epifaunal morphogroups continued in the Assemblage IV. The contribution of epifaunal forms drops to 72–56% of the assemblage (Fig. 4). In this assemblage, agglutinated foraminifers gradually increase their contribution to 6% of the assemblage (Fig. 2). Epifaunal *Ammodiscus cretaceus*, *Arenoturrisspirillina tunisiana* and *Recurvoides* spp. are common in the lower part of this interval while infaunal *Marssonella oxycona* blooms in the upper part of the Assemblage (Fig. 3). Assemblage IV indicates a gradual improvement of food supply and possibly calcium carbonate availability at the sea floor (Peryt *et al.*, 2002).

Assemblage V –middle and upper part of the *Parvularugoglobigerina eugubina* Zone (3,25-m-thick interval from 1,35 to 4,6 m above the impact layer)

This assemblage is characterised by a high diversity and low dominance of benthic genera (Figs 2, 3). The contribution of agglutinated forms increases to 8%. Within this group elongated forms gradually increase relative abundance up the interval (Fig. 5). *Gaudryina*, *Tritaxia* and *Clavulinoides* representatives of this group are long-term Lazarus taxa that reappear in this interval. *Ammobaculites* sp. and *Vulvulina gracillima* appear for the first time in the studied section within this assemblage (Fig. 3).

This assemblage indicates return to the pre-K/P boundary mesotrophic conditions at outer shelf –upper bathyal depths (Peryt *et al.*, 2002).

Assemblage VI –the uppermost part of the *Parvularugoglobigerina eugubina* Zone and *Parasubbotina pseudobulloides* Zone (5,0-m-thick interval from 4.6 to 9.6 m above the impact layer)

Assemblage VI is again highly diverse (Peryt *et al.*, 2002; figs 2, 3) and composed of mixed epifaunal and infaunal morphogroups (Fig. 4). Agglutinated forms make up 7–15% of the assemblages. Within the agglutinated component of this assemblage infaunal morphogroups dominate similar to as in Assemblage I. *Tritaxia* and *Gaudryina* along with *Spiroplectinella* and *Gaudryinopsis?* sp. 1 dominate within agglutinated foraminifers.

Assemblage VI is typical for marine environments with a flux of organic detritus that is sufficient to sustain infaunal bottom-dwellers (Peryt *et al.*, 2002).

DISCUSSION

Since Alvarez *et al.* (1980) proposed that a bolide impact occurred at the Cretaceous/Paleogene boundary, this time of mass extinctions has attracted much attention. Foraminifera are one of the most well-studied groups of marine organisms within this interval but most of the papers dealing with benthic foraminiferal assemblages focus on calcareous species. The agglutinated forms are still poorly understood.

During the last years, several authors have documented that benthic foraminiferal assemblages, in contrast to planktic foraminifera, did not suffer a mass extinction at the Cretaceous/Paleogene boundary, displaying lesser extinctions in deeper waters than at

shallower depths (e.g., Keller, 1988; Thomas, 1990; Kuhnt, 1990; Kaiho, 1992; Widmark & Malmgren, 1992). Benthic assemblages, however, exhibit various degrees of temporary faunal restructuring even in the absence of major extinction (e.g., Kuhnt & Kaminski, 1993; Speijer & van der Zwaan, 1994, 1996; Coccioni & Galeotti, 1994; Peryt *et al.*, 1997, 2002; Alegret *et al.*, 1999, 2001; Kouvenhaven, 2000). Keller (1988) proposed that a drop in sea level caused the benthic foraminiferal turnover across the K/P boundary, whereas most of authors suggest that the K/P benthic foraminiferal turnover is linked indirectly to the impact of an asteroid (e.g., Zachos *et al.*, 1989; Thomas, 1990; Widmark & Malmgren, 1992; Coccioni *et al.*, 1993; Kuhnt & Kaminski, 1993; Speijer & van der Zwaan, 1994; Coccioni & Galeotti, 1994; Peryt *et al.*, 1997, 2002; Alegret *et al.*, 1999, 2001).

Kuhnt & Kaminski (1993) and Peryt *et al.* (1997) documented changes in agglutinated foraminiferal assemblages across the K/P boundary interval. Kuhnt & Kaminski (1993) studied agglutinated foraminiferal assemblages from the K-P boundary interval from upper bathyal environments of the Basque Basin (Zumaya and Sopelana). These authors documented that uppermost Maastrichtian deep-water agglutinated foraminiferal (DWAf) assemblages were composed of both infaunal (*Spiroplectammina*, *Dorothia*) and epifaunal (suspension and detritus-feeders, e.g., astrophorids and ammodiscids) morphogroups. Non-calcareous forms with a coarsely agglutinated wall such as *Subreophax*, *Ammobaculites*, *Recurvoides* and *Saccammina* were the main component of the assemblage in the sediments directly above the boundary (P0 Zone). *Recurvoides* and *Saccammina* made up to 50% of the assemblages. Calcareous infaunal *Spiroplectammina* and *Dorothia* along with epifaunal *Recurvoides* dominated assemblages from the marly upper portion of the K/P boundary clay (Pa Zone).

According to these authors, the observed changes in the DWAf assemblages from upper bathyal environment reflect a response of benthic biota to a collapse of the food web and low carbonate availability for benthic organisms, resulting from the drastic decrease in primary productivity in the earliest Paleocene.

Peryt *et al.* (1997) showed that lower bathyal agglutinated foraminiferal assemblages in the Rotwandgraben section (eastern Alps) changed at the K/P boundary from mixed epifaunal –infaunal to assemblages dominated by epifaunal forms such as astrophorids, *Trochammina*, *Saccammina*, *Recurvoides* and *Ammodiscus* in the lower part of the P0 Zone. A comparison of DWAf assemblages from the K/P boundary interval from the Rotwandgraben section and those from the Basque region shows relatively high similarity between them with respect to both taxonomic composition and changes in relative abundances of dominant genera across the K/P boundary. Some differences were found as well. In the Rotwandgraben section, *Ammobaculites* is not recorded; *Recurvoides*, *Saccammina*, and *Subreophax* are present in the DWAf assemblages in lesser degree than in the Basque region. These differences are due to different depth of deposition of the two regions. The least affected group within agglutinated foraminifera by the K/P boundary crisis in the Rotwandgraben region similarly to as in the Basque region were epifaunal suspension-feeders and non-calcareous agglutinated

species living on the surface of the sediment. During the time of the collapse of the food web, these groups were privileged in access to a very limited food supply.

Similar results for calcareous benthic foraminifers were obtained by Thomas (1990) for the Weddell Sea, Widmark & Malmgren (1992) for the South Atlantic and Alegret *et al.* (2001) for the Gulf of Mexico.

In the Ain Settara section outer shelf - upper bathyal benthic foraminiferal assemblages did undergo a major restructuring at the K/P boundary. At this level several genera disappeared; some of them went extinct, whereas others reappeared in the lower Danian as Lazarus taxa (Peryt *et al.*, 2002). Late Maastrichtian mixed epifaunal and infaunal benthic foraminiferal assemblages were replaced at the base of the *Guembelitria cretacea* Zone (P0 Zone) by an impoverished assemblage composed almost entirely of epifaunal species. Agglutinated forms constitute up to 15% of the assemblage. Agglutinated epifaunal *Ammodiscus* and *Arenoturrisspirillina* increased their relative abundance in the 3-cm-thick layer directly overlying the impact layer where they co-occur along with infaunal calcareous agglutinated *Heterostomella*, *Bolivinospis*, *Gaudryina*, *Clavulinoides* and *Tritaxia*. All these taxa almost completely disappeared about 3-5 cm above the impact layer. In the higher part of the P0 Zone benthic foraminiferal assemblages are still dominated by epifaunal morphogroups but agglutinated foraminifers are almost absent, only rare specimens of *Marssonella*, *Recurvoides*, *Trochammina* and *Hyperammina* are found.

The assemblage from Zone P0 reflects a drastic collapse in food supply to the sea bottom and extreme oligotrophic conditions. The severe shortage of food resulted in the complete oxidation or consumption of all organic matter before it could be buried in the sediment, so that no food remained for infaunal taxa. Genera that prefer a high nutrient supply such as agglutinated *Heterostomella*, *Bolivinospis*, *Gaudryina*, *Clavulinoides*, *Tritaxia* and several calcareous hyaline forms disappeared. It is unusual, however, as also remarked by Speijer and van der Zwaan (1996) to find such high-dominance, low diversity faunas under oligotrophic, stress-free conditions. Keller (1988), Speijer & van der Zwaan (1996), and Kouwenhoven (2000) explained such unusual dominance at El Kef by assuming low oxygen conditions. They based this conclusion not on the morphology of the dominant benthic foraminiferal taxon, but on the occurrence of lamination in the sediments. It is difficult to understand how such low oxygen conditions could prevail at low productivity, and these authors assumed that the low oxygen conditions were caused by changes in circulation of the water masses. In our opinion, however, the lamination might have resulted from lack of burrowing macrofauna as a result of the mass extinction at the end of the Cretaceous. There are no indications in the geochemical data that low oxygen conditions occurred at Ain Settara (Tribovillard *et al.*, 2000). The dominant *Cibicidoides* are large, thick-walled and multi-chambered (Peryt *et al.*, 2002), in contrast to the typical low-oxygen, r-selected morphotypes, which generally have few chambers, small tests and thin walls. We therefore suggest that the low diversity of benthic foraminiferal assemblages of the earliest Danian may have been caused by environmental stress of another kind, changes in the phytoplankton

supplied to the benthic faunas (cf. Peryt *et al.*, 2002). At the K/P boundary the dominant primary producers, calcareous nannoplankton, suffered a major extinction (Romein & Smit, 1981), whereas the organic-walled dinoflagellates did not (Brinkhuis *et al.*, 1998). In the present oceans many organisms do not consume dinoflagellates, and the unusually low diversity faunas may have been under stress because of this change in the composition of food directly supplied from the photic zone. In our opinion (cf. Peryt *et al.* 2002), the benthic foraminiferal assemblages at Ain Settara do not indicate sea-level changes across the K/P interval, in agreement with Speijer and van der Zwaan (1996), Coccioni & Galeotti (1998) and Kouwenhoven (2000). These authors disagreed with the drop in sea level at or shortly before the K/P boundary as proposed by Keller (1988). We agree with Coccioni & Galeotti (1998) that there probably were no low-oxygen conditions after the K/P extinction, and that oxygenation thus did not cause faunal changes in benthic foraminifera. Our morphotype analysis suggests that the nature and abundance of the food supply to the sea-bottom floor conditioned the structure of the benthic foraminiferal assemblages and the faunal turnover (cf. Peryt *et al.*, 2002).

CONCLUSIONS

The following characteristics of marine environment may be suggested from the Ain Settara data (Fig. 6):

1. Late Maastrichtian Assemblage I in which epifaunal and infaunal morphogroups are mixed is typical for mesotrophic marine basins. The significant proportion of agglutinated infaunal genera *Heterostomella*, *Bolivinospis*, *Gaudryina*, *Clavulinoides* and *Tritaxia* with calcareous cement indicates that in the latest Maastrichtian supply of food particles and calcium carbonate was sufficient for infaunal benthic life at depths.

2. Assemblages II and III - very low abundant and low diversified - suggest an instantaneous collapse of food supply and extremely oligotrophic conditions. Evidence for a drastic decline in primary productivity is provided by a negative carbon isotope excursion across the K/P boundary (Zachos & Arthur, 1986; Keller & Lindinger, 1989); it was responsible for the very limited food flux to the sea floor, so that food particles were consumed at the sediment surface. The extreme dominance of few taxa (thus indicating stressed conditions) was probably not caused by low-oxygen conditions. Possibly, changes in the phytoplankton composition (from calcareous nannoplankton to dinoflagellates) could have caused the occurrence of such stressed faunas as well as the disappearance of calcareous cemented agglutinated foraminifers.

3. Assemblage IV is an interval wherein the diversity of both calcareous and agglutinated foraminifers increases, reflecting a gradual increase in the amount, and possibly in the diversity of the food supply.

4. Assemblages V and VI - interval characterised by high diversity and low dominance assemblages with a complex trophic structure. Long-term Lazarus taxa reappeared and new taxa appeared. This interval represents a return to pre-K/P boundary conditions, with nutrient levels fully mesotrophic.

The simultaneous occurrence of impact evidence (Tribovillard *et al.*, 2000), the catastrophic mass

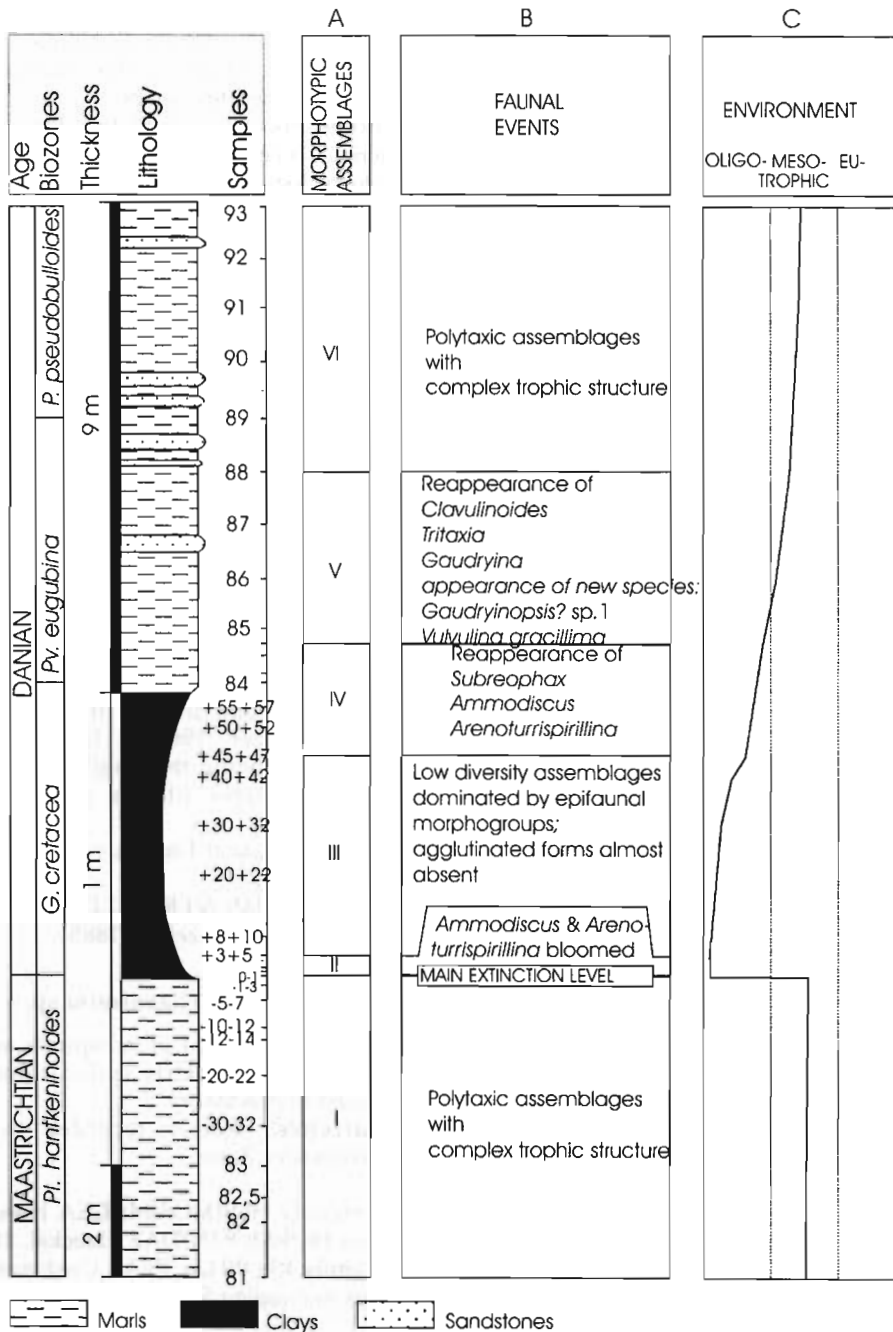


Figure 6. Summary diagram of morphotypic assemblages (A), faunal events (B) and fluctuations of trophic conditions across the Cretaceous/Paleogene boundary at the Ain Settara section (C).

extinction of planktic foraminifers (Arenillas *et al.*, 2000) and the drastic reorganisation of benthic foraminiferal assemblages at the K/P boundary at Ain Settara were very probably the result of the impact of an asteroid on the Yucatan peninsula, which caused a global drop in primary productivity, and thus triggered a benthic foraminiferal turnover.

TAXONOMY

Thirty five species of agglutinated foraminifers recorded in the studied interval are described. Loeblich & Tappan's (1987) systematics has been adopted in the present paper.

Order FORAMINIFERIDA Eichwald, 1830
 Suborder TEXTULARIINA Delage & Herouard, 1896
 Superfamily ASTORRHIZACEA Brady, 1881
 Family Bathysiphonidae Avnimelech, 1952
 Genus *Bathysiphon* M. Sars, 1872

Bathysiphon gerochi Mjatluk, 1966

Plate 1, fig. 1

Bathysiphon? sp. Geroch, 1960, p. 37, pl. 1, figs 16-19.
Bathysiphon (*Silicobathysiphon*) *gerochi* Mjatluk, 1966, p. 261, pl. 1, fig. 1a,b, pl. 2, fig. 4, pl. 3, fig. 1.
Bathysiphon gerochi Mjatluk. -Bubík, 1995, p. 79, pl. 1, figs 1-3, pl. 8, fig. 1. -Peryt *et al.*, 1997, pl. 1, figs 22-23.

Description. Test tubular, flattened, polished, with rare constrictions.

Occurrence. *Plummerita hantkeninoides* Zone.

Superfamily HIPPOCREPINACEA Rhumbler, 1895
Family HIPPOCREPINIDAE Rhumbler, 1895
Genus *Hyperammina* Brady, 1878

Hyperammina elongata Brady, 1878

Plate 1, Fig. 2

Hyperammina elongata H. B. Brady. –Cushman & Renz, 1946, p. 13, pl. 1, figs 9-10. –Samuel, 1977, p. 20, pl. 10, figs 1-2. –Kaminski *et al.*, 1988, p. 184, pl. 1, figs 14-15.

Description. Test elongate, large proloculus followed by undivided tubular chamber. Wall thin, finely agglutinated.

Occurrence. Rarely in the entire section.

Superfamily AMMODISCACEA Reuss, 1862
Family AMMODISCIDAE Reuss, 1862
Subfamily AMMOVOLUMMININAE Chernykh, 1967
Genus *Ammodiscus* Reuss, 1862

Ammodiscus cretaceus (Reuss, 1845)

Plate 1, fig. 4

Ammodiscus cretaceus (Reuss). –Sliter, 1968, pl. 42, pl. 1, fig. 8. –Gradstein & Berggren, 1981, p. 241, pl. 2, figs 12-13. –Kuhnt & Kaminski, 1993, p. 72, pl. 2, fig. 1. –Bak *et al.*, 1995, pl. 1, fig. D. –Bubík, 1995, p. pl. 10, fig. 5. –Rögl, 1995, p. 253, text-fig. 5, pl. 1, figs 12-13. –Kaminski *et al.*, 1996, p. 10, pl. 1, fig. 1-2. –Peryt *et al.*, 1997, pl. 2, fig. 13. –Widmark, 1997, p. 16, pl. 5, fig. C. –Kinsey, 2000, p. 231, pl. 3, fig. 1. –Alegret & Thomas, 2001, p. 276, pl. 1, fig. 5.

Description. Test planispiral, evolute, circular in outline, consisting of a globular proloculus and tubular post-prolocular second chamber very gradually and uniformly increasing in size with succeeding coils; wall agglutinated, very smooth and polished; aperture a simple opening at end of chamber.

Occurrence. Commonly in the entire section, except of lower part of the *Guembelitra cretacea* Zone where is not recorded.

Genus *Arenoturrspirillina* Tairov, 1956

Arenoturrspirillina tunisiana Peryt, Alegret & Molina, sp. n.

Plate 1, Figs 5, 6a,b, 7

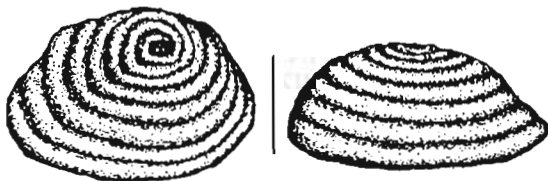


Figure 7. *Arenoturrspirillina tunisiana* sp.n., holotype, spiral and peripheral views, sample STWA +8+10; scale bar = 100 μ m

Ammodiscoides lajollaensis Sliter. –Keller, 1988, pl. 4, fig. 5.
Arenoturrspirillina sp.1. –Speijer & van der Zwaan, 1994, p. 44, pl. 9, fig. 3.

Derivation of name. Named after Tunisia, where the species was found for the first time.

Diagnosis. A small, coiled tubular form with a distinctly domed test shape.

Holotype. Specimen on Plate 1, Figs 6, 6A.

Material. Three specimens in the collection of the Institute of Paleobiology, Polish Academy of Sciences. Catalog no: ZPAL F.46/6 (holotype), ZPAL F. 46/5, 7 (paratypes)

Type locality and type horizon. The *Guembelitra cretacea* Zone of the El Haria Formation at Ain Settara, Tunisia.

Description. Test free, small, domed, consisting of a globular proloculus and tubular post-prolocular second chamber; tubular second chamber, increasing slowly in size, enrolled as in *Ammodiscus* but with moderately high trochospiral coiling thorough; 6-8 coils in the test; sutures distinct, depressed; aperture terminal, at open end of tube.

Dimensions of holotype. Diameter -0.25 mm, height -0.12 mm.

Remarks. *Arenoturrspirillina tunisiana* sp. n. differs from *A. aptica* Tairov, 1956 in having smaller size, lower number of coils in the test and in general shape which is dome-like; from *A. concavata* Samuel & Salaj, 1962 in having much smaller dimensions and higher number of coils in the test; from *Ammodiscoides lajollaensis* Sliter, 1968 in having moderately high trochospiral coiling thorough and having a relatively smaller diameter of the post-prolocular tubular chamber.

Occurrence. Lower Danian.

Subfamily AMMOVERTELLININAE Saidova, 1981
Genus *Glomospira* Rzehak, 1885

Glomospira sp.

Description. Several glomospirids with a proloculus followed by irregularly coiled tubular chamber are included to this taxon.

Occurrence. Rarely recorded in the *Plummerita hantkeninoides* Zone.

Superfamily HORMOSINACEA Haeckel, 1894
Family HORMOSINIDAE Haeckel, 1894
Subfamily REOPHACINAE Cushman, 1910
Genus *Subreophax* Saidova, 1975

Subreophax pseudoscalaria (Samuel, 1977)

Plate 1, Figs 8, 9

Reophax pseudoscalaria Samuel, 1977, p. 36, pl. 3, fig. 4.
Subreophax pseudoscalarius (Samuel). –Bolli *et al.*, p. 73, pl. 19, fig. 17.

Subreophax pseudoscalaria (Samuel). –Kaminski *et al.*, 1988, p. 187-188, pl. 3, figs 5-6.

Description. Test free, robust, consisting of up to 8, ovoid, diagonally embracing chambers.

Occurrence. Rarely recorded in the *Plummerita hantkeninoides* Zone.

Genus *Caudammia* Montanaro-Gallitelli, 1955

Caudammia excelsa (Dylązanka, 1901)

Plate 1, Fig. 3

Hyperammina excelsa Dylązanka, 1923, p. 66, pl. 1, fig.3.

Hormosina excelsa (Dylażanka). –Grün, 1969, p. 311, pl. 64, figs 1,2, pl. 65, fig. 1. –Hanzlíková, 1972, p. 36-37, pl. 3, fig. 5.

Description. Wall finely agglutinated, thick; short and broad chambers connected by stolon-like connections.

Occurrence. Rare in the entire section.

Caudamina ovula (Grzybowski, 1896)

Plate 1, Fig. 10

Reophax ovulum Grzybowski, 1896, p. 276, pl. 8, figs 19-21.

Hormosina ovulum (Grzybowski). –Geroch, 1960, p. 124, pl. 2, fig. 20, 21. –Gradstein & Berggren, 1981, p. 246-248, pl. 2, figs 1-2.

Carpathiella ovulum (Grzybowski). –Salaj *et al.*, 1976, p. 147, pl. 3, fig. 13.

Hormosina ovulum ovulum (Grzybowski). –Samuel, 1977, p. 33-34, pl. 3, fig. 11; pl. 16, fig. 5, pl. 17, figs 1-6, pl. 18, figs 1-4. –Geroch & Nowak, 1984, pl. 5, fig. 14. –Kaminski *et al.*, 1988, p. 186, pl. 2, fig. 10.

Hormosinella ovulum (Grzybowski). –Bolli *et al.*, 1994, p. 72, pl. 19, figs 17-19.

Caudamina ovulum (Grzybowski). –Rögl, 1995, p. 254. –Kuhnt & Kaminski, 1997, pl. 3, fig. 1.

Caudamina ovula (Grzybowski). –Koutsoukos, 2000, pl. 2, figs 22-24.

Description. Test finely agglutinated; surface smooth. Almost always found as single, oval to pear-shaped chambers with short necks; often compressed and deformed.

Occurrence. Rarely recorded in the *Plummerita hantkeninoides* Zone.

Superfamily LITUOLACEA de Blainville, 1827

Family HAPLOPHRAGMOIDIDAE Maync, 1952

Genus *Haplophragmoides* Cushman, 1910

Haplophragmoides eggeri Cushman, 1926

Plate 1, Fig. 12, 13, 14

Haplophragmoides eggeri Cushman, 1926, p. 583, pl. 15, fig. 1. –Cushman, 1946, p. 20, pl. 2, figs 9, 10. –Jurkiewicz, 1967, p. 77, pl. 4, fig. 11. –Gradstein & Berggren, 1981, p. 250, pl. 6, figs 1-4.

Description. Test free, with moderately coarse arenaceous walls and slightly roughened surface; planispiral, involute and moderately inflated; 6-7 chambers in the last whorl. Aperture an elongate equatorial slit at the base of the last chamber.

Occurrence. Rarely recorded in the *Plummerita hantkeninoides* Zone.

Haplophragmoides sp.

Plate 2, Fig. 10

Description. Test free, planispiral, involute, compressed; wall finely agglutinated; periphery slightly lobulate; 7-8 chambers in the last whorl; sutures poorly visible; aperture an equatorial slit at the base of last chamber.

Occurrence. Rarely recorded in the *Plummerita hantkeninoides* Zone.

Haplophragmoides? sp.

Plate 1, Fig. 11

Description. Test free, smooth, planispiral, compressed, composed of 6 wide chambers; sutures indistinct, horizontal. Aperture obscured and not

clearly visible. The generic assignment is uncertain due to the indistinct nature of the aperture.

Occurrence. Rarely recorded in the *Plummerita hantkeninoides* Zone.

Family LITUOLIDAE de Blainville, 1827

Subfamily AMMOMARGINULININAE Podobina, 1978

Genus *Ammobaculites* Cushman, 1910

Ammobaculites sp.

Description. Test fairly coarse, medium, elongate, an apparently coiled initial portion followed by a straight, uniserial part.

Occurrence. Rarely recorded in the *Parvularugoglobigerina eugubina* Zone.

Superfamily HAPLOPHRAGMIACEA Eimer & Fickert, 1899

Family AMMOSPHAEROIDINIDAE Cushman, 1927

Subfamily RECURVOIDININAE Alekseychik-Mitskevich, 1973

Genus *Recurvoides* Earland, 1934

Recurvoides sp.

Plate 2, Fig. 1a,b

Description. Test free, streptospiral, gradually changing in the coiling direction, subglobular in outline; wall finely agglutinated, surface somewhat rough; chambers globose to elongate-ovate; sutures depressed; aperture a slightly oval areal opening.

Occurrence. Rarely recorded in the *Parvularugoglobigerina eugubina* Zone.

Recurvoides spp.

Description. A variety of apparently streptospiral forms attributable to this genus have been recorded from the studied interval.

Occurrence. Rare to common in the entire section.

Superfamily SPIROPLECTAMMINACEA Cushman, 1927

Family SPIROPLECTAMMINIDAE Cushman, 1927

Subfamily SPIROPLECTAMMININAE Cushman, 1927

Genus *Bolivinopsis* Yakovlev, 1891

Bolivinopsis rosula (Ehrenberg, 1854)

Plate 2, Fig. 3

Spiroplectamina rosula (Ehrenberg). –Kaptarenko-Chernousova *et al.*, 1963, p. 68-69, pl. 20, figs 1a, b. –Gawor-Biedowa, 1980, p. 14, pl. 1, fig. 12. –Gawor-Biedowa, 1992, p. 29, pl. 1, figs 11, 12.

Bolivinopsis rosula (Ehrenberg). –Vaptzarova, p. 58, pl. 1, figs 1-4.

Bolivinopsis clotho (Grzybowski). –Speijer & van der Zwaan, 1994, p. 44, pl. 1, fig. 1.

Description. Test free, narrow and slender, lenticulate in section; early portion planispirally coiled, later chambers biserially arranged; biserial stage is of nearly constant width throughout; sutures oblique, almost flush; walls agglutinated, fine-grained;

periphery angular with faint keel; aperture low arch at the base of last chamber.

Occurrence. Commonly recorded in the *Plummerita hantkeninoides* Zone; gone extinct in the basal part of the *Guembelitra cretacea* Zone.

Genus *Spiroplectamina* Cushman, 1927

Spiroplectamina sp.

Plate 2, Figs 12a,b

Description. Test free, slender, elongate, with an indistinct early stage (planispiral?), later biserial, with almost parallel sides; chambers in biserial part numerous, rectangular and inflated, increasing very slowly in size as added; wall finely agglutinated; sutures depressed; aperture an opening at the base of last chamber.

Occurrence. Rarely recorded in the *Plummerita hantkeninoides* Zone.

Spiroplectamina? sp.

Plate 2, Fig. 13

Description. A few biserial specimens with early portion broken, with low, slightly inflated chambers and depressed, straight and oblique sutures are assigned to this taxon.

Occurrence. Rarely recorded in the *Plummerita hantkeninoides* Zone.

Genus *Spiroplectinella* Kisel'man, 1972

Spiroplectinella esnaensis (Le Roy, 1953)

Plate 2, Fig. 4

Spiroplectamina esnaensis Le Roy, 1953, p. 50, pl. 1, figs 11-12. -Shahin, 1990, p. 498, pl. 1, fig. 10.

Spiroplectinella esnaensis (Le Roy). -Speijer & van der Zwaan, 1994, p. 147, pl. 3, fig. 1.

Description. Test free, small, rapidly increasing in width from the initial part of the test, rhomboid in section; early portion planispirally coiled, later chambers biserially arranged; chambers low, arched, rapidly increasing in width as added, sutures very slightly depressed, arched; walls agglutinated, fairly coarse-grained; periphery angular and even; aperture low arch at the base of last chamber.

Occurrence. Rarely recorded in the *Plummerita hantkeninoides* and *Parasubbotina pseudobulloides* Zones.

Spiroplectinella laevis (Roemer, 1841)

Plate 2, Fig. 2

Spiroplectamina laevis (Roemer). -Kuhnt & Moullade, 1991, pl. 2, Figs F, G. -Kuhnt & Kaminski, 1993, p. 75, pl. 6, Fig. 5. -Bubík, 1995, p. 87, pl. 14, Figs 6a-7. -Widmark, 1997, p. 19, pl. 6, Fig. C.

Spiroplectamina cf. *laevis* (Roemer). -Kuhnt, 1990, p. 325, pl. 6, Fig. 15.

Spiroplectamina sp. A. -Widmark & Malmgren, 1992, p. 103, pl. 10, Fig. 5.

Description. Test free, kite-shaped, rhomboid in section; early portion planispirally coiled, later chambers biserially arranged; sutures oblique, straight

to arcuate and depressed; walls agglutinated, fairly coarse-grained; periphery angular and even; aperture low arch at the base of last chamber.

Occurrence. Rarely recorded in the *Plummerita hantkeninoides* Zone and commonly in the *Parasubbotina pseudobulloides* Zone.

Subfamily VULVULININAE Saidova, 1981

Genus *Vulvulina* d'Orbigny, 1826

Vulvulina gracillima ten Dam & Sigal, 1950

Plate 2, Fig. 5

Vulvulina gracillima ten Dam & Sigal, 1950, p. 31, pl. 2, fig. 1. -Salaj *et al.*, 1976, p. 148, pl. 3, figs 1, 2.

Description. Test free, wall very finely agglutinated, smoothly finished, compressed; early chambers arranged in a small spiral, later becoming biserial and uniserial in adult portion; biserial part is composed of 5-6 pairs of narrow chambers and tapered; uniserial part forms 2-3 chambers, with parallel sides and horizontal, depressed sutures; periphery acute, keeled and even; aperture terminal.

Occurrence. Rarely recorded in the *Parvularugoglobigerina eugubina* Zone.

Superfamily TROCHAMMINACEA Schwager, 1877

Family TROCHAMMINIDAE Schwager, 1877

Subfamily TROCHAMMININAE Schwager 1877

Genus *Trochammina* Parker & Jones, 1859

Trochammina sp. 1

Plate 2, Figs 8a-c

Description. Test free, medium-sized, trochospiral; spiral side convex with curved sutures; umbilical side flattened with indistinct, radial sutures; periphery rounded; 5-6 petaloid chambers in the final whorl increasing gradually in size as added; wall coarsely agglutinated; aperture obscured.

Occurrence. Rarely recorded in the *Parasubbotina pseudobulloides* Zone.

Trochammina sp. 2

Plate 2, Fig. 9

Description. Test free, very small, trochospiral, biconvex; the spiral side is only slightly convex, the umbilical side is inflated convex; periphery rounded; 6-7 chambers in the final whorl increasing rapidly in size as added; sutures depressed and straight; wall agglutinated; aperture obscured.

Occurrence. Rarely recorded in the *Parasubbotina pseudobulloides* Zone.

Trochammina spp.

Remarks. A variety of generally trochospiral forms with between 5-7 chambers attributable to this genus have been recorded in the studied material.

Occurrence. Rarely recorded in the entire section.

Superfamily VERNEUILINACEA Cushman, 1911

Family VERNEUILINIDAE Cushman, 1911

Subfamily VERNEUILINOIDINAE Suleymanov, 1973

Genus *Gaudryinopsis* Podobina, 1975

Gaudryinopsis? sp. 1

Plate 2, Figs 6a,b, 11a,b

Description. Test free, fairly coarse, initially triserial or highly trochospiral followed by a biserial portion with nearly parallel sides; chambers slightly appressed, sutures depressed; aperture indistinct.

The exact generic name assignment is unclear because of the poor preservation often encountered, particularly in the nature of the initial part of test. Other possible generic assignments may be *Gerochammina* Neagu or *Karrerulina* Finlay.

Occurrence. *Plummerita hantkeninoides* Zone and *Parasubbotina pseudobulloides* Zones.

Subfamily VERNEUILINOIDINAE Suleymanov, 1973
Genus *Gaudryina* d'Orbigny, 1839

Gaudryina aisana ten Dam & Sigal, 1950

Plate 3, Fig. 2

Gaudryina (*Siphogaudryina*) *aisana* ten Dam & Sigal, 1950, p. 31, pl. 2, figs 2a-b.

Description. Test free, agglutinated, pyramidal and triangular-quadrate in section; periphery acute; triserial part short, comprising about one-fifth of the entire test; chambers indistinct in the triserial part, distinctly inflated in the biserial portion, 8 to 10 in numbers; depressed, distinct sutures in the biserial part; aperture a low opening at the inner margin of last chamber.

Occurrence. Rarely recorded in the *Plummerita hantkeninoides* Zone.

Gaudryina laevigata Franke, 1914

Plate 3, Figs 1, 3

Gaudryina laevigata Franke. –Cushman, 1946, p. 33, pl. 8, fig. 4. –Hanzlíková, 1972, p. 52, pl. 11, fig. 2. –Gawor-Biedowa, 1980, p. 16, pl. 1, fig. 11. –Gawor-Biedowa, 1992, pp. 33-34, pl. 3, figs 1,2.

Description. Test free, robust, finely agglutinated, early portion triserial, triangular in section, angles subacute; chambers indistinct in the triserial part, distinctly inflated and overlapping in the biserial portion, sutures in biserial part flush, later depressed; aperture an arched opening at the inner margin of final chamber.

Occurrence. Commonly recorded in the *Plummerita hantkeninoides* Zone and *Parasubbotina pseudobulloides* Zones; rarely found in the *Parvularugoglobigerina eugubina* Zone; not present in the *Guembelitra cretacea* Zone except of its basal part.

Gaudryina pyramidata Cushman, 1926

Plate 3, Figs 4, 5

Gaudryina (*Pseudogaudryina*) *pyramidata* Cushman, 1946, p. 36, pl. 8, fig. 14.

Gaudryina pyramidata Cushman. –Salaj *et al.*, 1976, p. 149, pl. 2, figs 9, 10. –Hercogová, 1984, p. 109, pl. 2, fig. 1, pl. 3, figs 7-9, text-fig. 9 (1-5). –Keller, 1988, pl. 4, figs 13-16. –Kaminski *et al.*, 1988, p. 194, pl. 8, fig. 7. –Gawor-Biedowa, 1992, p. 34, pl. 3, fig. 10.

Description. Test free, elongate, pyramidal, rather coarsely agglutinated, initially triserial and triangular

in transverse section, subrectangular and biserial in later portion; angles acute; chambers indistinct in the triserial part, slightly inflated in the biserial portion of the test, sutures somewhat depressed; aperture an arched opening at the inner margin of final chamber.

Occurrence. Commonly recorded in the *Plummerita hantkeninoides* Zone and *Parasubbotina pseudobulloides* Zones; rarely found in the *Parvularugoglobigerina eugubina* Zone; not present in the *Guembelitra cretacea* Zone except of its basal part.

Genus *Verneuilina* d'Orbigny, 1839

Verneuilina sp.

Remarks. Test free, triserial throughout, triangular in section, angles acute; aperture at the base of last chamber.

Occurrence. Rarely recorded in the *Plummerita hantkeninoides* Zone.

Subfamily BARBOURINELLINAE Saidova, 1981
Genus *Heterostomella* Reuss, 1866

Heterostomella austinana Cushman, 1946

Plate 3, Figs 6, 7, 8, 9

Heterostomella austinana Cushman, 1946, p. 41, pl. 11, figs 2-7. *Trifarina esnaensis* Le Roy. –Keller, 1988, pl. 3, fig. 15 –16. *Heterostomella austinana* Cushman. –Said & Kenawy, p. 126, pl. 1, fig. 45. –Speijer & van der Zwaan, 1994, p. 46, fig. 2.

Description. Test free, elongate, slightly tapering; early portion of the test triserial, later becoming biserial, fairly distinct; the angles of the chambers very thin, usually eroded, leaving large depressions in linear series; sutures rather indistinct; aperture terminal, rounded, with a distinct neck.

Occurrence. Commonly recorded in the *Plummerita hantkeninoides* Zone; becomes extinct in the basal part of the *Guembelitra cretacea* Zone.

Family TRITAXIIDAE Plotnikova, 1979
Genus *Tritaxia* Reuss, 1860

Tritaxia globulifera (ten Dam & Sigal, 1950)

Plate 3, Figs 14, 15, 16

Pseudoclavulina globulifera ten Dam & Sigal, 1950, p. 32, pl. 2, figs 5-7. –Said & Kenawy, 1956, p. 125, pl. 1, fig. 30. –Shahin, 1990, pl. 7, fig. 12.

Clavulinoides globulifera (ten Dam & Sigal). –Kaminski *et al.*, 1988, p. 194, pl. 8, figs 14-15.

Pseudoclavulina farafraensis Le Roy. –Shahin, 1990, pl. 7, fig. 10, 11.

Description. Test free, elongate, initially triserial and triangular in section followed by a uniserial portion of 3-5 rounded and inflated chambers; the last one more elongated, terminated by a small, rounded aperture on a short neck.

Remarks. The specimens of this species differ slightly from the type in having broader angles in the triangular part.

Occurrence. Commonly recorded in the *Plummerita hantkeninoides*, *Parvularugoglobigerina eugubina* and *Parasubbotina pseudobulloides* Zones; not present in the *Guembelitra cretacea* Zone except in its basal part.

Superfamily TEXTULARIACEA Ehrenberg, 1838
 Family EGGERELLIDAE Cushman, 1937
 Subfamily EGGERELLINAE Cushman, 1937
 Genus *Martinotiella* Cushman, 1933

Martinotiella paleocenica Cushman, 1946

Plate 2, Fig. 7

Martinotiella paleocenica Cushman, 1946, p. 82, pl. 18, fig. 1; 1951, p. 9-10, pl. 2, fig. 19.

Description. Test free, elongate, cylindrical, initially trochospiral, later portion with a short irregular biserial stage, followed by a uniserial portion of 2-4 barrel-shaped chambers. Wall finely agglutinated, smoothly finished. Aperture terminal, rounded, with a short neck.

Occurrence. Rarely recorded in the *Plummerita hantkeninoides* Zone.

Subfamily DOROTHIINAE Balakhmatova, 1972
 Genus *Marssonella* Cushman, 1933

Marssonella oxycona (Reuss, 1860)

Plate 3, Fig. 13

Dorothia oxycona (Reuss). –Sliter 1968, p. 50, pl. 3, fig. 13a,b. –Hanzlíková 1972, p. 57, pl. 11, figs 8, 10. –Salaj *et al.*, 1976, p. 150, pl. 1, fig. 5. –Kaminski *et al.* 1988, p. 195, pl. 9, fig. 9. –Peryt & Wyrwicka, 1991, fig. 7. 28. –Bąk *et al.* 1995, p. 20, pl. 3, figs d-g.

Marssonella oxycona oxycona (Reuss). –Bolli *et al.* 1994, p. 94, pl. 25, figs 5-6. –Peryt *et al.* 1997, pl. 4, fig. 13. –Alegret & Thomas, p. 290-291, pl. 8, fig. 14.

Description. Test free, conical, circular in cross section, and with pointed initial part; wall agglutinated, smoothly finished; initially trochospiral, later biserial; chambers not inflated; sutures flush to slightly depressed; aperture a low opening at the base of the last chamber.

Occurrence. Recorded in the *Plummerita hantkeninoides*, *Guembelitra cretacea* and *Parvularugoglobigerina eugubina* Zones.

Subfamily PSEUDOGAUDRYININAE Loeblich & Tappan, 1985
 Genus *Clavulinoides* Cushman, 1936

Clavulinoides trilatera (Cushman, 1926)

Plate 3, Figs 10, 11, 12

Clavulinoides trilatera (Cushman) Cushman. –Cushman, 1946, p. 38, pl. 9, figs 10-16.

Clavulinoides trilatera (Cushman). –Said & Kenawy, 1956, p. 126, pl. 1, fig. 39. –Kaminski *et al.*, 1988, p. 195, pl. 9, fig. 2.

Tritaxia aspera (Cushman). –Widmark, 1997, p. 21, pl. 7, fig. C, not Cushman.

Clavulinoides trilatera (Cushman). –Alegret & Thomas, 2001, p. 283, pl. 5, figs 6-8.

Description. Test free, elongate, triangular thorough, with the sides nearly parallel; triserial at the beginning, later becoming uniserial; five or more chambers in the uniserial part, increasing very slightly in size as added; wall agglutinated, rather smoothly finished; aperture rounded

Occurrence. Commonly recorded in the *Plummerita hantkeninoides*, *Parvularugoglobigerina eugubina*

and *Parasubbotina pseudobulloides* Zones; not present in the *Guembelitra cretacea* Zone except of its basal part.

ACKNOWLEDGEMENTS

This study was supported for Laia Alegret and Eustoquio Molina by the Spanish Ministry of Education and Technology, Project BTE 2001-1809. We thank Ignacio Arenillas and Jose A. Arz for providing the biostratigraphical data, and Christian Dupuis for providing samples from the section. Miroslav Bubík and Wolfgang Kuhnt are thanked for critical reading of the manuscript and several valuable suggestions and comments. We are also grateful to Mike Kaminski for helpful suggestions.

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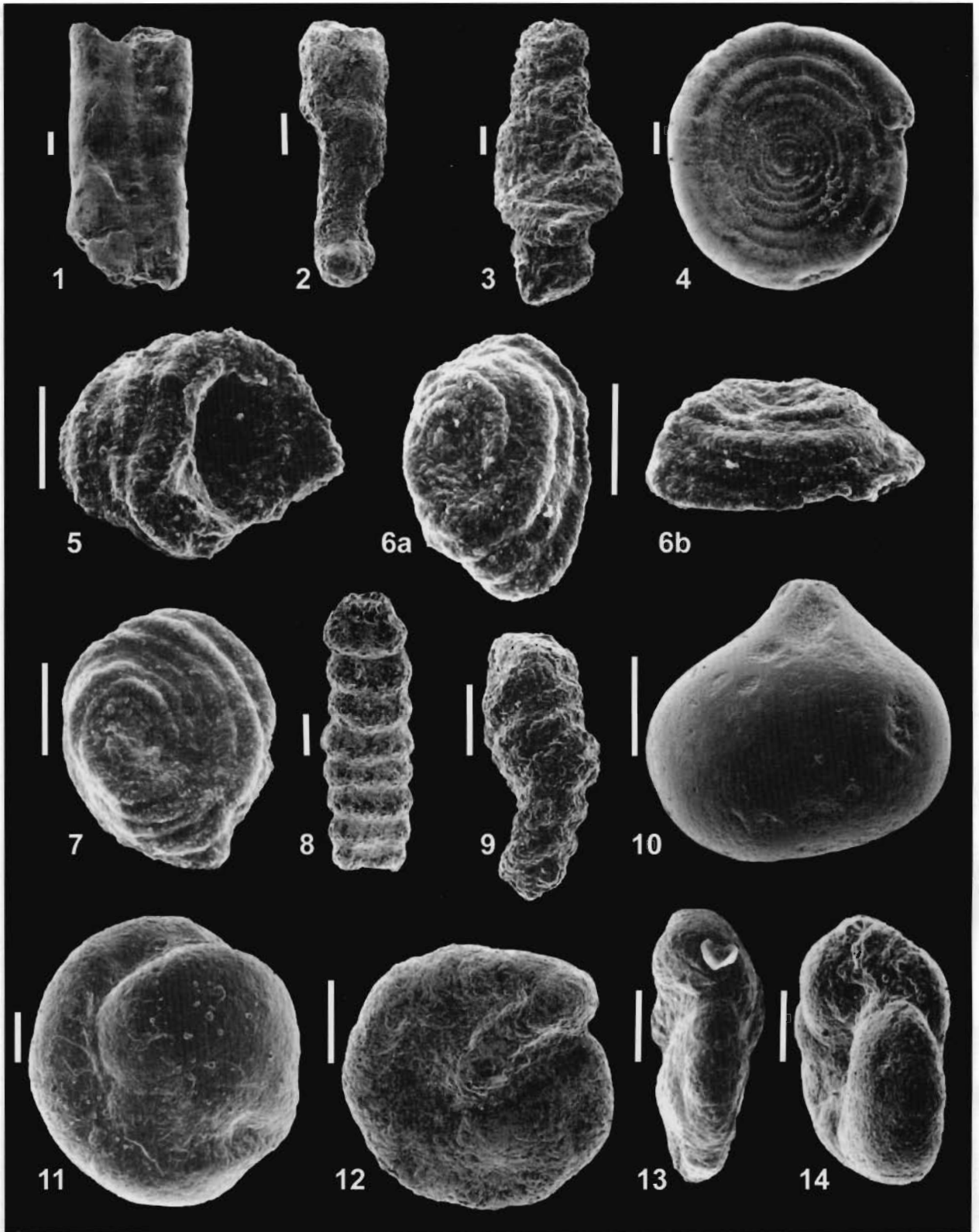


Plate 1. 1. *Bathysiphon gerochi* Mjatluk, 1966; STW 81; ZPAL F.46/1. 2. *Hyperammina elongata* Brady, 1878; STW 86; ZPAL F.46/2. 3. *Caudammina excelsa* (Dyląganka), 1898; STW 36; ZPAL F.46/3. 4. *Ammodiscus cretaceus* (Reuss, 1845); STW 36; ZPAL F.46/4. 5,6a,b,7. *Arenoturrisspirillina tunisiana* Peryt, Alegret & Molina, sp.n.; STWA 3 - ZPAL F.46/5, STWA +8+10 - ZPAL F.46/6, STWA 84 - ZPAL F.46/7. 8,9. *Subreophax pseudoscalaria* (Samuel, 1977); STW 73; ZPAL F.46/8,9. 10. *Caudammina ovula* (Grzybowski, 1896); STW 83; ZPAL F.46/10. 11. *Haplophragmoides?* sp.; STW 61; ZPAL F.46/11. 12,13,14. *Haplophragmoides eggeri* Cushman, 1926; STW 73, 79; ZPAL F.46/12-14. Scale bar = 100 μ m.

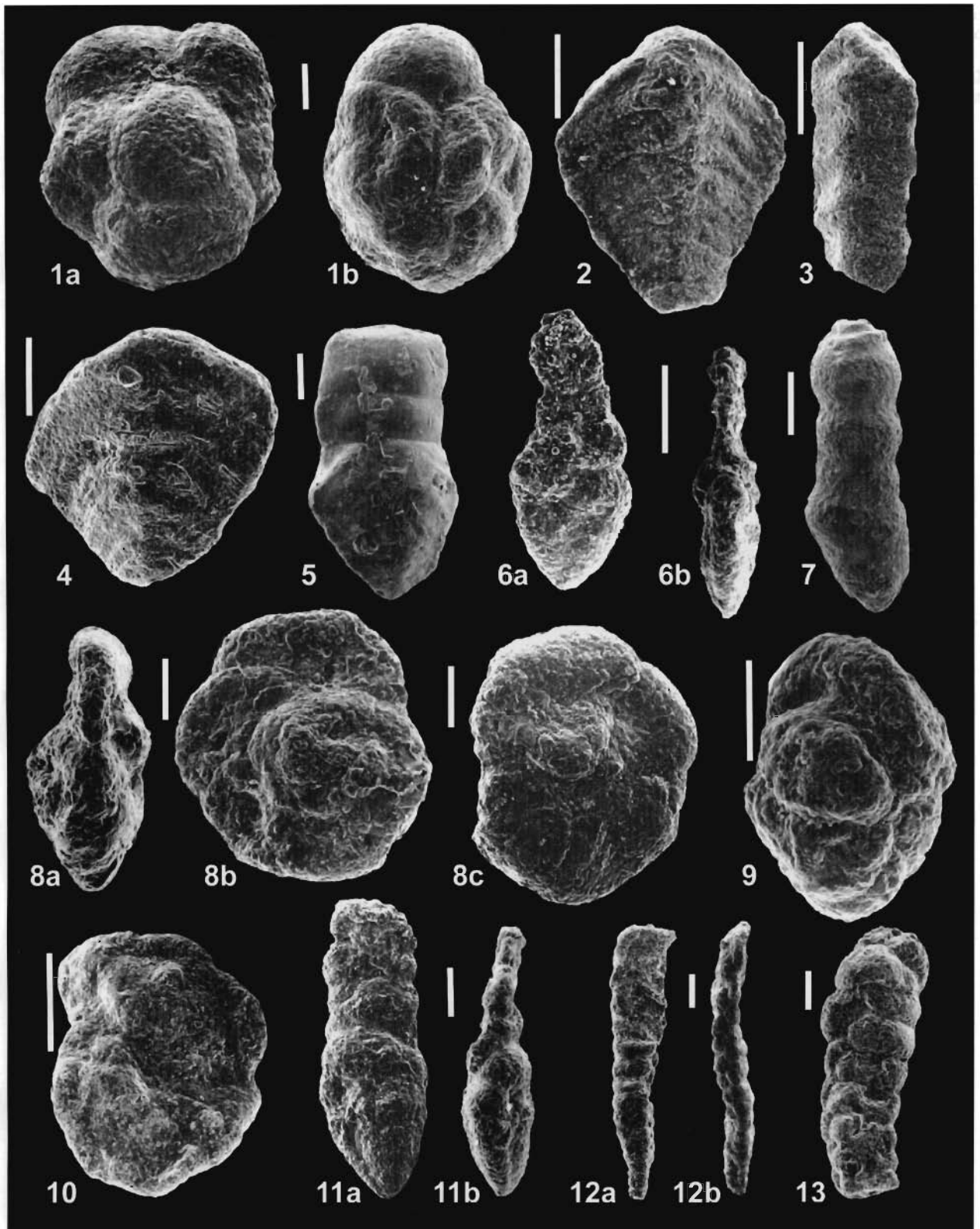


Plate 2. 1. *Recurvoides* sp., 1964; STW 84,2; ZPAL F.46/15. 2. *Spiroplectinella laevis* (Roemer, 1841); STW 92; ZPAL F.46/16. 3. *Bolivinopsis rosula* (Ehrenberg, 1854); STW 66,5; ZPAL F.46/17. 4. *Spiroplectinella esnaensis* (le Roy, 1953); STW 46; ZPAL F.46/18. 5. *Vulvulina gracillima* ten Dam & Sigal, 1953; STW 88; ZPAL F.46/19. 6a,b, 11a,b. *Gaudryinopsis?* sp. 1; STW 73, 78; ZPAL F.46/20-21. 7. *Martinotiella palaeocenica* Cushman, 1946; STWA-5-7; ZPAL F.46/22. 8a-c. *Trochammina* sp. 1; STW 90; ZPAL F.46/23. 9. *Trochammina* sp. 2; STW 92; ZPAL F.46/24. 10. *Haplophragmoides* sp.; STW 79; ZPAL F.46/25. 12a,b. *Spiroplectammina* sp.; STWA-12-14; ZPAL F.46/26. 13. *Spiroplectammina?* sp.; ZPAL F.46/27. Scale bar = 100 μ m.

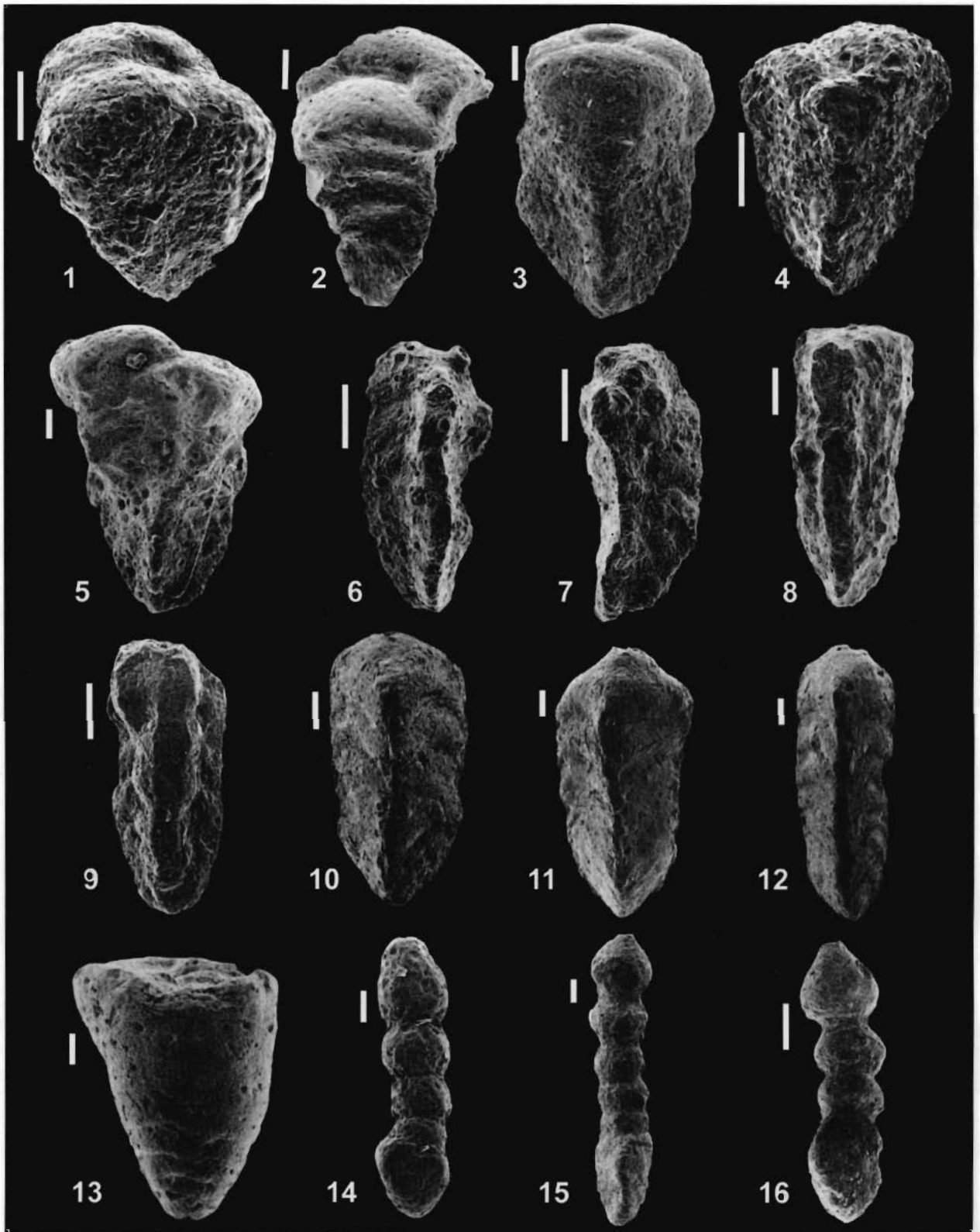


Plate 3. 1,3. *Gaudryina laevigata* Franke, 1914; ZPAL F.46/28-29. 2. *Gaudryina aisana* ten Dam & Sigal, 1950; STW 36; ZPAL F.46/30. 4,5. *Gaudryina pyramidata* Cushman, 1926; STW 86, 90; ZPAL F.46/31-32. 6,7,8,9. *Heterostomella austinana* Cushman, 1946; STW 82, STWA-10-12; ZPAL F.46/33-36. 10,11,12. *Clavulinoides trilatera* (Cushman, 1926); STW 61, 80, 82; ZPAL F.46/37-39. 13. *Marssonella oxycona* (Reuss, 1860); STW 82; ZPAL F.46/40. 14,15,16. *Tritaxia globulifera* (ten Dam & Sigal, 1950); STW 80, 89; ZPAL F.46/41-43. Scale bar = 100 μm .