

Benthic foraminiferal response to the Cenomanian–Turonian and Cretaceous–Paleogene boundary events

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Abstract. The present paper summarizes previously published results of my studies on the Cenomanian–Turonian and Cretaceous–Paleogene changes in benthic foraminiferal assemblages. The recorded changes indicate that the rate and intensity of restructuring of benthic foraminiferal populations during the Cenomanian–Turonian Boundary Event (CTBE) and Cretaceous–Paleogene Boundary Event (KTBE) strongly depended on the duration and severity of environmental stress.

A stepwise extinction within benthic foraminiferal assemblages, a bloom of infaunal and semi-infaunal morphotypes during the CTBE and a relatively long-lasting survival interval (the *Whiteinella archaeocretacea* chron) most likely reflect the decline in oxygenation level of the bottom waters at the end of the *Rotalipora cushmani* chron and persistence of these unfavourable conditions during the *Whiteinella archaeocretacea* chron. A catastrophic type of mass extinction within benthic foraminiferal assemblages, extinction or temporary emigration of most of infaunal morphogroups during the KPBE and a relatively short survival interval are interpreted to be the result of a sudden breakdown in food supply as the consequence of a sudden collapse in primary productivity, probably resulting from the impact of the K–P asteroid.

Key words: Cenomanian, Turonian, Cretaceous, Paleogene, benthic foraminifera, mass extinctions, recovery

The Cenomanian–Turonian and Cretaceous–Paleogene boundaries coincide with major changes, both biotic and abiotic, over much of the Earth. The Cenomanian–Turonian boundary event (CTBE) is a relatively minor Phanerozoic mass extinction (Raup & Sepkoski, 1984; Kauffman & Hart, 1996) and is related to a 2nd — order sequence boundary (Kauffman, 1985). The CTBE is closely associated in time with the Oceanic Anoxic Event II (OAE II) that was probably triggered by areal expansion of oxygen-poor waters (see, e.g., Schlanger & Jenkyns, 1976; Arthur et al., 1987; Leckie et al., 2002). The C–T mass extinction is recognized as a stepped mass extinction (Koch, 1980; Kauffman, 1988), and patterns of survival and recovery from the Cenomanian–Turonian mass extinction for different groups have been proposed already (e.g., Harries & Kauffman, 1990; Koutsoukos et al., 1990). In order to estimate the response of benthic foraminifera to the CTBE and to establish a pattern of recovery of this group from the C–T mass extinction, two borehole sections in Poland, Sawin (Peryt & Wyrwicka, 1991) and Puławy (Peryt & Wyrwicka, 1993), and two outcrop sections in northern Spain, Menoyo (Peryt & Lamolda, 1996) and Ganuza (Lamolda & Peryt, 1995), were studied.

One of the greatest mass extinctions in the Earth's history took place at the Cretaceous–Paleogene (K–P) boundary. After extensive discussion, it now seems to be generally accepted that a bolide collided with the Earth, probably at Chicxulub (Mexico, Yucatan Peninsula), leaving a huge crater and precipitating a mega-tsunami and various other environmental effects that would have been deleterious to life (Culver, 2003). While planktic foraminifera suffered almost complete extinction (e.g., Smit, 1982; Arenillas et al., 2000), benthic forms were not so severely affected by the biotic crisis, at least in terms of extinction (e.g., Kuhnt & Kaminski, 1993; Speijer & van der Zwaan, 1994). Causes of extinction and/or restructuring of benthic foraminiferal assemblages across the K–P boundary has been explained in different ways. The purpose of my studies was to trace the response of benthic foraminiferal assemblages to the K–P boundary event (KPBE) in two selected sections: deep-water (middle bathyal to abyssal) Rotwandgraben section in the Eastern Alps, Austria (Peryt et al., 1997), and intermediate-water (outer neritic to mid-

dle bathyal) Adin Settara section, Central Tunisia (Peryt et al., 2002, 2004), aiming to explain the relation between changes in foraminiferal assemblages and abiotic events at the K–P boundary.

The present paper summarizes the published results of my studies on the above-listed selected sections of the Cenomanian–Turonian and Cretaceous–Paleogene boundaries (Peryt & Wyrwicka, 1991, 1993; Lamolda & Peryt, 1995; Peryt & Lamolda, 1996; Peryt et al., 1997, 2002, 2004). I applied a model for survival and recovery after mass extinction that was proposed by Harries & Kauffman (1990) and Kauffman & Erwin (1995). They divided the period between mass extinction and restructuring of communities and ecosystems into three intervals:

1) the late phases of the mass extinction, during which time Lazarus taxa disappear; taxa that will survive the extinction and persist through to the recovery interval show significant changes in population structure, progenitor taxa arise;

2) a survival interval with (a) an early crisis phase characterized by rare survivors (often completely devoid of fauna) and blooms of disaster taxa (b), and (c) a later population expansion phase characterized by population blooms among ecological opportunists, expansion of populations among surviving resident and immigrant species, and the early return of some Lazarus taxa (d);

3) the recovery interval with (a) an early phase characterized by widespread return of Lazarus taxa and (b) a later phase of recovery characterized by more rapid, continuous increase in diversity as new lineages arise and radiate, and speciation continues among surviving lineages. The recovery phase eventually results in basic restructuring of communities and ecosystems.

Material

Nineteen samples were taken from a 6 m thick sequence in the Sawin borehole, 31 samples from a 20 m thick sequence in the Puławy borehole, 26 samples from a 55 m thick sequence in the Menoyo section and 25 samples from a 26.5 m thick sequence in the Ganuza section. The studied Cenomanian–Turonian boundary intervals comprise the upper part of the *Rotalipora cushmani* and the *Whiteinella archaeocretacea* planktic foraminiferal zones (Sawin, Menoyo — Fig. 1), the upper part of *Rotalipora brotzeni*, the *R. reicheli*, the *R. cushmani* and the *Whiteinella archaeocretacea* zones

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(Puławy), and the upper part of the *Rotalipora cushmani* and the lower part of the *Whiteinella archaeocretacea* zones (Ganuza).

The Sawin borehole is located at the periphery of the East European platform, within the Podlasie–Lublin Horst, and the Puławy borehole is located in the Border Synclorium that is adjacent to the East European Platform. Both studied sections originated in an epicontinental sea. The Cenomanian deposits are condensed in that part of Poland, although they are five times thicker at Sawin and Puławy than in the classical Annapol on Vistula section (Marcinowski, 1980; Peryt, 1983; Walaszczyk, 1987). Both Menoyo and Ganuza sections paleogeographically belong to the Navarro-Cantabrian line, which corresponded to a middle/outer shelf setting during the Late Cretaceous. During the Cenomanian and Turonian more than 2000 m of sediment accumulated there (Lamolda et al., 1987), and thus both Spanish sections belong to the most expanded Cenomanian–Turonian boundary intervals.

A total of 22 samples were analyzed from the Rotwandgraben section (from 2.5 m below to 1 m above the K–P boundary) and at the Adin Settara section, a total of 34 samples were analyzed from the section 2.5 m below to 9.6 m above the K–P boundary. The studied interval at Rotwandgraben encompasses the uppermost part of the *Abathomphalus mayaroensis* Zone, P0 Zone (*Guembelitra cretacea* and *Globoconusa conusa* subzones), *Parvularugoglobigerina eugubina* Zone and *Subbotina pseudobulloides* Subzone (Peryt et al., 1993, 1997). The studied interval at Adin Settara encompasses the upper part of the *Plummerita hantkeninoides* Zone, *Guembelitra cretacea* Zone (P0 Zone), *Parvularugoglobigerina eugubina* Zone and the lower part of the *Parasubbotina pseudobulloides* Zone (Fig. 2; Peryt et al., 2002, 2004).

The Rotwandgraben section is exposed within the flyschoid Upper Campanian–Lower Eocene Upper Complex of the Gosau Beds (Lahodinsky, 1989). The sequence of the Maastrichtian and Paleocene sediments in the Gosau Basin indicates sedimentation in a deep-sea environment above the CCD (Lahodinsky, 1989). The Adin Settara section is located within the Maastrichtian–Thanetian El Haria Formation that is dominantly marly, sometimes clayey, with few calcareous beds; the section is located about 50 km south of the El Kef K–P boundary stratotype and it occupies more continental platform position (Dupuis et al., 2001) than El Kef sediments that were deposited in a neritic-upper bathyal setting (e.g., Keller, 1988; Kouwenhoven, 2000).

Methods

P/B ratio (relative abundances of planktic and benthic foraminifers in the assemblages) and relative abundances of benthic species within assemblages were calculated and H(S) — the Shannon-Weaver heterogeneity index of benthic foraminiferal assemblages — was computed.

Benthic foraminifers were identified at the generic level largely following Loeblich & Tappan (1987). Allocation of foraminiferal taxa into morphogroups was largely performed following Jones & Charnock (1986), Corliss & Chen (1988) and Nagy et al. (1995). However, benthic foraminifera may migrate within the sediment during ontogeny, and in addition, the broad classification is often disordered by motile species and thus a distribution of benthic foraminifers should be regarded as a dynamic process. Motile species may be found in different microhabitats in response to changing environmental conditions and food

supply. This group of species able to change habitats from epifaunal to infaunal is regarded as highly adaptable and tolerant (Linke & Lutze, 1993).

Results and interpretation

Samples from the *Rotalipora cushmani* Zone of two studied Polish sections yielded foraminiferal assemblages of which 10–30% are planktic taxa (Peryt & Wyrwicka, 1991, 1993). The benthic fauna is of a relatively high diversity and is typical of the late Cenomanian. In the zone, several Cenomanian species (such as *Lingulogavelinella orbiculata*, *L. formosa*, *Arenobulimina anglica*, *Tritaxia macfadyeni*) disappear and some others (e.g., *Dorothia gradata* or *Gavelinella berthelini*) appear. However, the most dramatic change in the benthic foraminiferal assemblage, with the majority of the typical Cenomanian groups becoming extinct, is connected with the boundary between *Rotalipora cushmani* and *Whiteinella archaeocretacea* Zones. At the boundary, *Gavelinella intermedia*, *G. cenomanica*, *G. baltica*, *Arenobulimina advena*, *Tritaxia pyramidata*, *Plectina cenomana*, and *P. ruthenica* become extinct. *Lenticulina rotulata* is much reduced in abundance. Some other species temporarily disappear, then reappear in the Lower Turonian. At the same time *Lingulogavelinella globosa* appears (Peryt & Wyrwicka, 1991, 1993). Two planktic species *Rotalipora cushmani* and *Rotalipora greenhornensis* also become extinct at the boundary. A characteristic feature of foraminiferal assemblages from this interval is the exceptionally poor state of preservation of the tests; almost all of the specimens show surface pitting and traces of dissolution.

At the base of the *Whiteinella archaeocretacea* Zone, a rapid increase in the percentage of planktic foraminifera is recorded, and high P/B ratio continues upwards. Low species diversity and domination by 2–4 species are recorded in the assemblages of benthic foraminifera in the lower part of *Whiteinella archaeocretacea* Zone. *Lingulogavelinella globosa* and *Gavelinella berthelini* are the main contributors to the assemblages in the very basal part of the zone. Higher up, *Lenticulina rotulata* recovers and a gradual upward increase in diversity of benthic foraminiferal assemblages is recorded (Peryt & Wyrwicka, 1991, 1993).

Tests of calcareous foraminifers from the marly limestones show traces of dissolution. This is interpreted as due to the dissolution caused by bottom waters which were strongly impoverished in oxygen during their deposition (Jarvis et al., 1988; Peryt & Wyrwicka, 1991). It seems that encroaching oxygen-minimum zone to that part of the Danish-Polish Trough, which was probably shallower than the Chalk Sea, had changed rapidly the oxygenation level within most part of the water column. However, in the studied sections, complete anoxia never occurred. The response of foraminiferal biota was varied: extinction of some species of benthic and planktic foraminifers, temporary absence of other species and decrease not only in diversity, but also in abundance of planktic foraminifers. The recolonisation of the vacated niches during the early Turonian was slow (in contrast to the microplankton) and is most likely a result of the low migration rates of the microbenthos (cf. Leary & Peryt, 1991).

The Cenomanian–Turonian boundary interval in the Menoyo section yields quite abundant foraminifera, both planktic and benthic. H(S) — the Shannon-Weaver heterogeneity index — is generally high — >2.0. P/B ratio values vary from 60% to 100%. Depth distribution of recorded benthic foraminiferal genera (cf. Murray, 1991) combined with quan-

titative data on studied fauna indicate an outer shelf to upper bathyal water depth during latest Cenomanian/early Turonian time at the Menoyo section (Peryt & Lamolda, 1996).

Values of H(S) are between 1.1 and 2.3, and P/B ratio fluctuates significantly (12%–80%) in the uppermost Cenomanian in the Ganuza section. Combined quantitative data on foraminiferal assemblages indicate a shelf water depth during latest Cenomanian time at the Ganuza section (Lamolda & Peryt, 1995).

Study on the Menoyo section indicated that the major faunal turnover occurred in Late Cenomanian, during late *Rotalipora cushmani* chron (Fig. 1). In the lower part of the section there is a clearly visible accelerated stepwise disappearance within benthic foraminiferal fauna. In the topmost part of the *Rotalipora cushmani* Zone 33 species disappeared; some of them went extinct, others disappeared only temporarily. In the same interval one can observe stepped appearance of many species. Recorded changes in the morphotypic composition of benthic foraminiferal assemblages indicate fluctuation of dysaerobic to anoxic conditions at Menoyo during late Cenomanian–early Turonian time. In oxygen-depleted waters and probably with higher organic content infauna and semi-infauna made 70 to 96% of the populations. When oxygen conditions ameliorated epifauna began to expand. Complete anoxia occurred when benthic foraminifera were not present in the sediment. Abundance fluctuations of dominant species, infaunal/semi-infaunal to epifaunal ratio and

distribution of benthic foraminifera in the section allow us to regard the lowermost part of the section as representing the late phase of mass extinction; higher part of the section represents survival interval. Stepped extinction of dominant species characterizes late phase of mass extinction and early phase of survival interval. None of the dominant species was classified as representing Lazarus taxa. To the late phase of mass extinction there are also related progenitor species (Peryt & Lamolda, 1996).

Within the survival interval the following subdivisions may be discerned (Fig. 1):

a) a very short interval, completely devoid of benthic foraminifera, corresponding to a “dead” zone of Harries and Kauffman (1990);

b) a short interval, in which along with opportunistic taxa and species which are going to extinct by the end of this interval, disaster species appeared;

c) a relatively long interval dominated mainly by opportunistic species; in the upper of this interval first Lazarus taxa return.

Recorded changes in composition of benthic foraminiferal assemblages in the Ganuza section include stepped extinction of several foraminiferal species both benthic and planktic, sudden extinction of a large group of epifaunal rosalinids and conorbinids and recolonization of vacant niches by 2–4 infaunal and/or semi-infaunal species. These changes most likely reflect the decline of the oxygenation level of the bottom waters at the end of the *Rotalipora cushmani* Zone and the persistence of these unfavourable

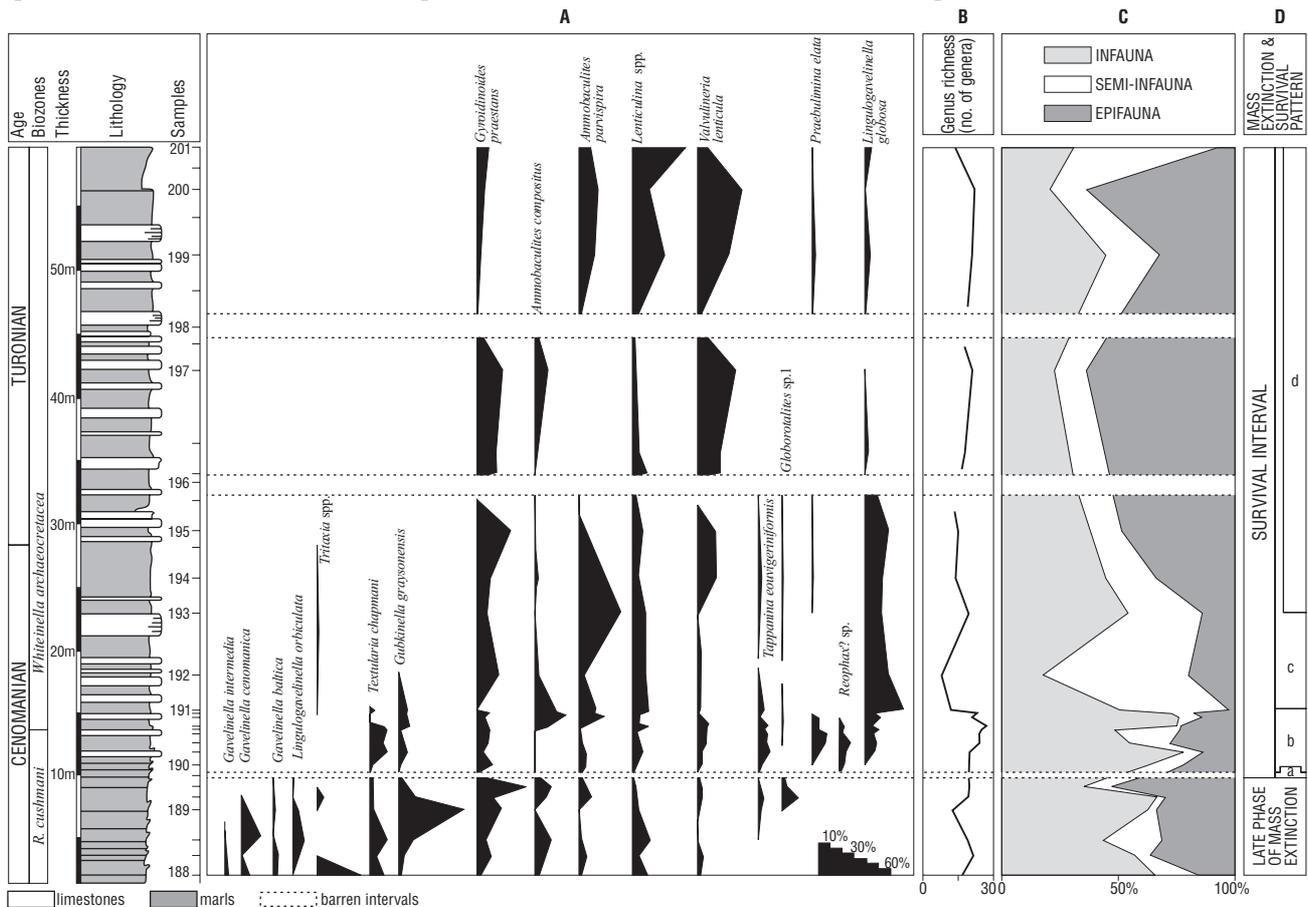


Fig. 1. Changes in benthic foraminiferal assemblage composition across the C-T boundary in the Menoyo section; A — relative abundances of dominant benthic foraminiferal species; B — foraminiferal taxonomic diversity (number of genera); C — proportion of infaunal, semi-infaunal and epifaunal morphogroups within benthic foraminiferal assemblages; D — extinction and survival pattern: (a) interval devoid of benthic foraminifera, (b) interval where disaster forms appeared, (c) interval where assemblages are dominated by opportunistic taxa; in the upper part of this interval first Lazarus taxa return (d)

conditions in the early *Whiteinella archaeocretacea* Zone. In the Ganuza section, however, complete anoxia never occurred; in this site bottom waters were only oxygen-restricted during the latest Cenomanian-earliest Turonian (Lamolda & Peryt, 1995).

Significant faunal (and geochemical — see Peryt et al., 1993) changes are observed in the *Guembelitra cretacea* Subzone in the Rotwandgraben section in Austria (Peryt et al., 1997). Deep-water agglutinated foraminiferal (DWAf) assemblages in the *Guembelitra cretacea* Subzone are impoverished in abundance and diversity in comparison with those from under- and overlying sediments. The assemblage from the lower part of the Subzone displays very low abundance and diversity. The assemblage from the upper part of the Zone is composed almost entirely of epifaunal morphogroups (Peryt et al., 1997). The low abundance of foraminifera in those assemblages, as well as change in their morphotypic composition, indicates a sudden breakdown of food supply to benthic organisms.

In the Adin Settara section the level of extinction and faunal turnover of benthic foraminifers corresponds to the “impact layer” at the base of the *Guembelitra cretacea* Zone (Fig. 2). The *Guembelitra cretacea* Zone and the lowermost part of the *Parvularugoglobigerina eugubina* Zone represent a survival interval; the recovery interval encompasses the middle and upper part of the *Parvularugoglobigerina eugubina* Zone and the *Parasubbotina pseudobulloides* Zone (Peryt et al., 2002, 2004). The survival interval is composed of:

1) a very thin interval at the base of the *Guembelitra cretacea* Zone devoid of benthic foraminifers (a), overlain by also thin interval with scarce, low diversity, high dominance-assemblages dominated by epifaunal morphotypes; blooming *Ammodiscus* is interpreted as disaster species (b);

2) an interval of low diversity with stressed assemblages dominated by opportunistic taxa, mainly epifaunal *Cibicidoides* (c) — lower and middle part of the *Guembelitra cretacea* Zone;

3) an interval where short-term Lazarus taxa reappeared and epifaunal morphotypes decreased in relative abundance (d), during the upper part of the *Guembelitra cretacea* Zone and the lowermost part of the *Parvularugoglobigerina eugubina* Zone (Fig. 2).

The recovery interval is characterised by high diversity and low dominance assemblages with a complex trophic structure. Long-term Lazarus taxa reappeared (e) during the middle and upper part of the *Parvularugoglobigerina eugubina* Zone and *Parasubbotina pseudobulloides* Zone. This interval represents a reversal to the pre-K-P boundary conditions, with nutrient levels fully mesotrophic.

Discussion and conclusions

Late Cenomanian low oxygen tolerant benthic foraminiferal faunas have been recorded from many regions that show very similar morphotypic associations; the faunal differences which nevertheless exist most probably reflect provincialism within benthic foraminifers. The studied Polish and Spanish sections represent a late phase of mass

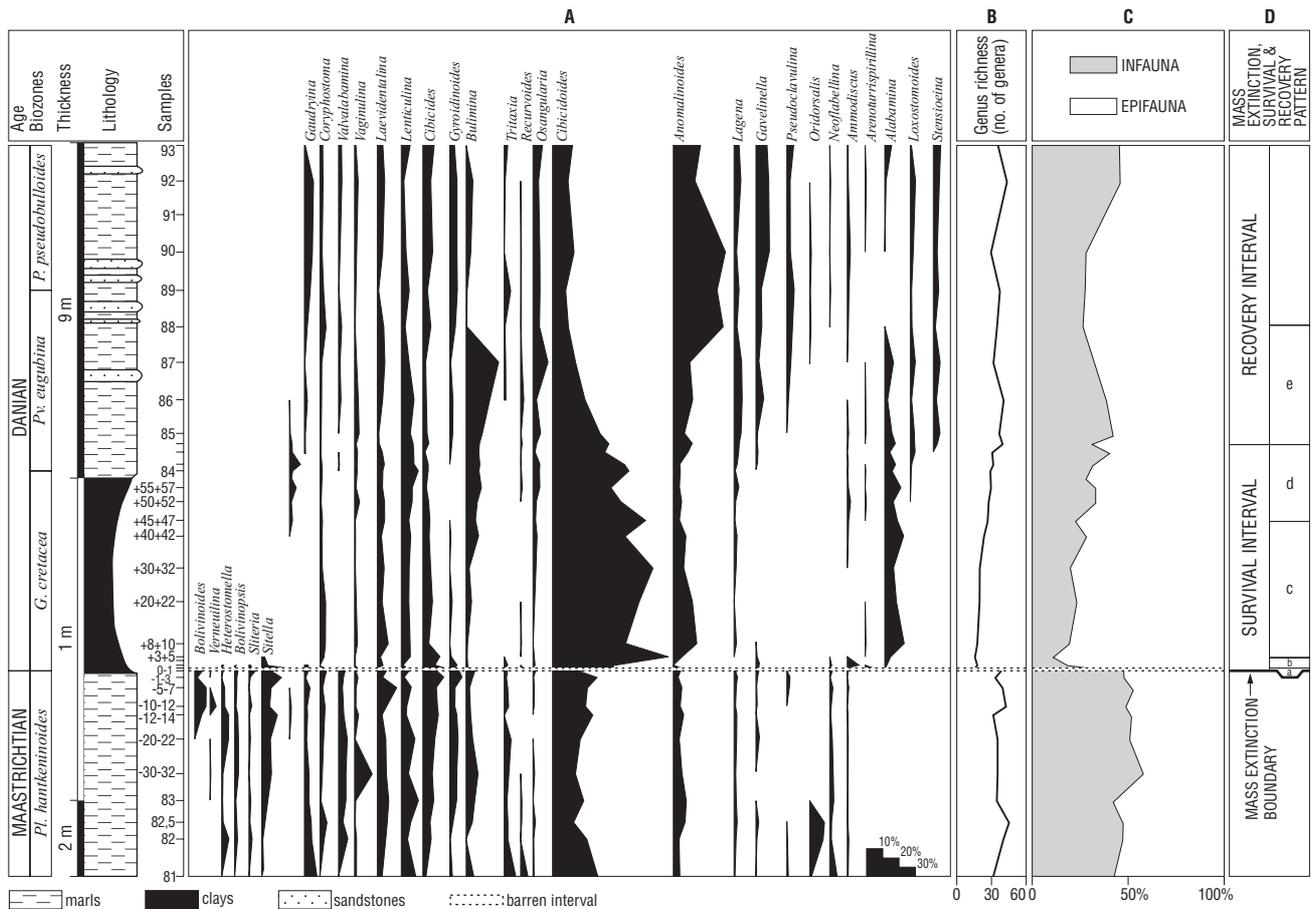


Fig. 2. Changes in benthic foraminiferal assemblage composition across the K-P boundary in the Adin Settara section; A — relative abundances of dominant and common of benthic foraminiferal genera; B — foraminiferal taxonomic diversity (number of genera); C — proportion of infaunal and epifaunal morphogroups within benthic foraminiferal assemblages; D — extinction, survival and recovery pattern; (a) interval devoid of benthic foraminifera, (b) interval where disaster forms appeared, (c) interval where assemblages are dominated by opportunistic taxa, (d) interval where first Lazarus taxa return, (e) interval where long-term Lazarus taxa return

extinction and survival intervals. In the survival interval there can be discerned a brief interval immediately following the final major extinction event, in which benthic biota are absent — a “dead zone”; followed by an also relatively brief interval characterized by the population bloom of disaster taxa, and finally an interval characterized by the domination of benthic assemblages by a few opportunistic taxa. The recorded changes in benthic foraminiferal assemblages including stepped extinction of several foraminiferal species, temporary disappearance of many rare and common species, bloom of disaster species in the lower part of the survival interval and opportunistic species in the upper part of the survival interval most likely reflect a decline of the oxygenation level of the bottom waters at the end of the *Rotalipora cushmani* Zone and the persistence of these unfavourable conditions in the *Whiteinella archaeocretacea* Zone.

Interval in which faunal turnover was observed represents the most stressful environmental conditions; increasing oxygen depletion caused stepped extinction or temporary disappearance from the area of several species and in the peak of the event when complete anoxia occurred temporary disappearance of all benthic species. When oxygen conditions a little ameliorated, benthic foraminifera reappeared. However, in the early Turonian still two times bottom waters became anoxic (Peryt & Lamolda, 1996). Because at that time benthic communities were dominated by opportunistic species well adapted to low oxygen conditions, these brief anoxic periods did not cause extinctions within the communities but only temporary disappearances of benthic biota.

Low content of benthic foraminiferal epifauna in the uppermost Cenomanian confirms strong oxygen deficiency in bottom waters and probably increased amount of organic matter. Improvement of oxygen conditions in bottom waters is reflected by expansion of epifauna which characterize areas with lesser food availability.

Late Maastrichtian benthic foraminiferal communities changed in composition in response to sea-level change in the late Maastrichtian continuing into the Danian, and these changes were punctuated by a bolide impact at the K-P boundary (Culver, 2003). The impact caused a global drop in primary productivity, and thus triggered benthic foraminiferal turnover. In the K-P boundary interval from upper bathyal environments of the Basque Basin (Zumaya and Sopolana), uppermost Maastrichtian DWAf assemblages were composed of both infaunal and epifaunal morphogroups (Kuhnt & Kaminski, 1993). Noncalcareous forms with a coarsely agglutinated wall were the main component of the assemblage in the sediments directly above the boundary (P0 Zone). Kuhnt & Kaminski (1993) concluded that 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.

Study on the Rotwandgraben section (Peryt et al., 1997) showed that lower bathyal agglutinated foraminiferal assemblages changed from mixed epifaunal-infaunal to assemblages dominated by epifaunal forms 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 (Peryt et al., 1997) due to different depth of deposition in the two regions. Within agglutinated

foraminifera, the least affected group by the K-P boundary crisis in the Rotwandgraben region (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.

In the Adin 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 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 epifaunal calcareous *Cibicidoides*. In the higher part of the P0 Zone benthic foraminiferal assemblages are still dominated by epifaunal morphogroups but agglutinated foraminifera are almost absent (Peryt et al., 2004).

The assemblage from the P0 Zone 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. 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. The benthic foraminiferal assemblages at Adin Settara do not indicate sea-level changes across the K-P interval (Peryt et al., 2002) and there probably were no low-oxygen conditions after the K-P extinction, and thus oxygenation did not cause faunal changes in benthic foraminifera. The morphotype analysis suggests that the nature and abundance of the food supply to the sea-bottom floor controlled the structure of the benthic foraminiferal assemblages and the faunal turnover (cf. Peryt et al., 2002, 2004).

There exist substantial differences between many of the mass extinctions in terms of their biotic, lithologic and geochemical factors (e.g., Kauffman & Walliser, 1990; Walliser, 1996), but despite these differences, the broad pattern of repopulation appears to be comparable between biotic crises (e.g., Harries & Little, 1999). Benthic foraminiferal response to the Cenomanian-Turonian and Cretaceous-Paleogene boundary events (CPBE and KPBE, respectively) in the studied sections indicates that:

□ The Cenomanian-Turonian mass extinction is characterized as stepwise extinction within benthic foraminiferal assemblages; 50–60% of species went extinct or temporarily disappeared during the CTBE.

□ Infaunal and semi-infaunal morphotypes were the forms which bloomed during the CTBE.

□ The Cretaceous-Paleogene mass extinction represents a catastrophic type of extinction within benthic foraminiferal assemblages, although rate of extinction is only moderate. About 30% species did not cross the Cretaceous-Paleogene boundary; some of them return later as Lazarus taxa.

□ Infaunal morphotypes were the forms which suffered the most during the KPBE.

□ Repopulation was much slower after the CTBE than after the KPBE.

□ There is no great difference in extinction rates between shallow and deep basins both in the case of CTBE and KPBE.

□ In both cases, within the survival interval, the same repopulation pattern can be observed: a very short interval devoid of benthic foraminifera (easy to overlook if sampling is not dense enough) followed by an interval in which disaster and eurytopic species bloomed, then an interval in which opportunistic species became abundant. In the topmost part of this interval first Lazarus taxa return (Figs 1, 2).

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