Palaeogeography, Palaeoclimatology, Palaeoecology, 66 (1988): 153–171
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

BIOTIC TURNOVER IN BENTHIC FORAMINIFERA ACROSS THE CRETACEOUS/TERTIARY BOUNDARY AT EL KEF, TUNISIA

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(Received May 3, 1987; revised and accepted December 14, 1987)

Abstract

Keller, G., 1988. Biotic turnover in benthic foraminifera across the Cretaceous/Tertiary boundary at El Kef, Tunisia, Palaeogeogr., Palaeoclimatol., Palaeoecol., 66: 153–171.

The Cretaceous/Tertiary boundary section exposed near El Kef, Tunisia is the most complete boundary sequence known to date. It contains nearly 1 m of black and gray boundary clay containing planktic foraminiferal Zone P0a, b, 2 m of clayey shales of P1a (*Globigerina eugubina*) Zone and 4 m of shales and marls of P1b (*G. taurica*) Zone. Quantitative analysis of the benthic foraminiferal fauna suggests that deposition during the latest Cretaceous occurred in an upper slope to outer shelf environment which shallowed at the K/T boundary to an outer to middle shelf depth and shallowed further by P1b time to mid-shelf depth. A major reduction in benthic diversity occurred near the K/T boundary with about 50% of the fauna disappearing. Diversity remained an average of 37% lower during deposition of the first 3 m of sediment above the boundary (P0a, b–P1a) and productivity was very low. Surviving and thriving foraminifers during this interval were primarily low oxygen tolerant epifaunal and infaunal species. A sharp decrease in the low oxygen tolerant fauna and appearance of a shallow mid-shelf fauna at about 4 m above the boundary (P1b Zone) signals a second regression, return to higher oxygen levels and higher productivity. Although the environmental effects of the K/T boundary event can be inferred from benthic faunas, the ultimate cause remains elusive. Faunal changes prior to and the long recovery period after the K/T boundary are difficult to explain by a single impact hypothesis.

Introduction

It is generally recognized that the Cretaceous/Tertiary (K/T) boundary section near El Kef in northwestern Tunisia is one of the most complete boundary sections known to date (Salaj, 1975, 1980; Perch-Nielsen, 1981a, b; Perch-Nielson et al., 1982; Romein and Smit, 1981; Smit, 1982). Nevertheless, very few foraminiferal studies have been published on Tunisian faunas despite excellent field outcrop exposures and well preserved faunas (for a review see Aubert and Berggren, 1976). There are two main reasons: (1) Access to the sections is restricted and (2) there is a general misconception that the El Kef section represents an anomalous fauna. This view has been generated by the anomalously thick (50 cm black) boundary clay representing Zone P0 followed by a 50 cm dark grey clay and 2 m thick clayey shale representing Zone P1a or *Globigerina eugubina* Zone (Smit, 1982). The three meters representing these two zones are usually not present in pelagic deep-sea sequences, or are compressed into a few centimeters of sediment (Thierstein, 1981, 1982; Perch-Nielsen et al., 1982; Smit, 1982; Gerstel et al., 1987).

Most of the deep-sea sections and most presently onshore sections have part of the Cretaceous/Tertiary boundary record missing (Officer and Drake, 1983). This is either due to a hiatus or non-deposition of sediment as a result

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of low productivity and/or dissolution (rising carbonate compensation depth (CCD)) above the K/T boundary. For these reasons, it is more likely that a complete stratigraphic record can be recovered from shallow shelf sequences. The El Kef section is therefore anomalous only in that it represents a more complete stratigraphic record than is known from the deep sea.

As more shallow onshore sequences are being studied in detail more such complete K/T boundary sections will be found. One such section has already been studied at Brazos River, Texas. Jiang and Gartner (1986) reported on the nannofossils, Hansen (1982) on macrofossils, and foraminifera are presently being studied by the present author. Planktic foraminifers show a 1 m sequence (Zones PO–Pla) above the K/T boundary that is stratigraphically similar to El Kef. However, most of Zone Pla (*Globigerina eugubina*) is missing. Other shallow water sites that appear relatively complete are the Braggs section in Alabama (Jones et al., 1987) and sections in the Negev, Israel (Magaritz et al., 1985). The purpose of this study is to document the benthic foraminiferal faunas quantitatively in order to elucidate the biotic and environmental changes across the Cretaceous/Tertiary boundary. No such studies have been published of the El Kef faunas, or any other K/T boundary sequence, except for DSDP Site 516 (Dailey, 1983).

Geological setting

The El Kef section is located about 7 km from the town of El Kef in northwest Tunisia (Fig.1). The upper Maastrichtian to Paleocene strata are part of the El Haria Formation which overlies the upper Cretaceous limestone of the Abiod Formation. Upper Maastrichtian sediments are composed of calcareous shales and marls. A reddish 1–3 mm thin ferruginous layer marks the contact between Cretaceous shales and marls and the overlying 50 cm thick black boundary clay which represents the earliest Paleocene planktic foraminiferal Zone POa, b (Keller, 1988). The black clay grades into 50 cm dark grey clay followed by 3 m of grey shales representing Zone Pla (*Globigerina eugubina*). About 6 m above the K/T boundary carbonate content sharply increases in more marly sediments.

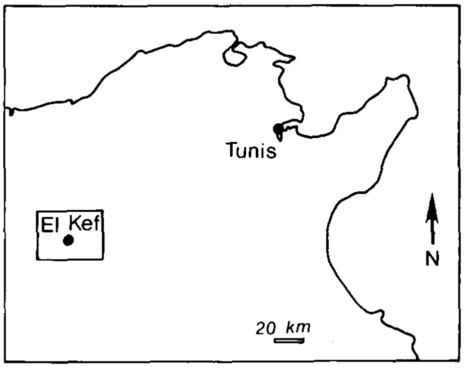


Fig.1. Location of section studied.

Aubert and Berggren (1976) noted that the sea level regression at the end of the Maastrichtian generally caused a hiatus in lowermost Tertiary sediments of the El Haria Formation southeast of El Kef. However, no hiatus was observed at El Kef. On the contrary, the most complete K/T boundary sequence known to date has been observed here. The El Kef section is more complete than the Gredero section at Caravaca, Spain (Perch-Nielsen, 1981a, b, Perch-Nielsen et al., 1982; Smit, 1982), the Brazos River section in Texas (Jiang and Gartner, 1986), or the Braggs section of Alabama (Jones et al., 1987).

During late Cretaceous to earliest Tertiary time El Kef was located on an upper slope to outer shelf region. During the early Tertiary deposition continued on a shelf region to the southwest whereas shallower shelf and lagoonal conditions prevailed to the southeast. Aubert and Berggren (1976) studied primarily the shallower southeastern sections which may explain the hiatuses they observed. In addition, their samples are widely spaced which may account for some missing zones.

Material and methods

Samples were collected by members of the International Committee on Stratigraphy, Cretaceous–Paleocene working group and splits distributed to interested parties by K. Perch-Nielsen and T. Romein. Sample numbers used in this report represent original numbers given by the collecting team. Samples were analyzed at 20-cm intervals below the K/T boundary, at 5–10 cm intervals for the first 1.0 m above the boundary, at 20-cm intervals between 1.0 m and 3.0 m, and at 50-cm intervals between 3.0 and 7.0 m above the boundary. For this benthic foraminiferal study a total of 35 samples were analyzed between 4 m below the K/T boundary and 7.0 m above the boundary. Stratigraphically the interval spans from the top of the Maastrichtian planktic foraminiferal *Abathomphalus mayaroensis* Zone through the earliest Danian Zones P0a, (*Guembelitria cretacea*) P0b, (*Globoconusa conusa*), P1a (*Globigerina eugubina*) and P1b (*Eoglobigerina* spp. and *Globigerina taurica*) (Keller, 1988). Thus, a complete Cretaceous-Tertiary boundary sequence is present.

Samples were processed by standard micropaleontological techniques (Keller, 1980). In general sediments were not easy to disaggregate and repeated soaking in water with dilute H_2O_2 followed by several washings were necessary. Both benthic and planktic foraminifers are common to abundant and generally well preserved. Benthic foraminifers frequently have a sugary texture and are coated with Fe and Mn oxides particularly in the 2 m of clayey sediment immediately above the boundary. This suggests postdepositional alteration. However, scanning electron micrograph studies of shell structures of selected benthics (*Anomalinoides acuta, A. preacuta*) show that although some solution has taken place and early chambers show growth of calcite crystals, much of the original calcite appears to be present.

Benthic foraminifers were analyzed quantitatively based on representative splits of about 300 specimens in the size fraction greater than 150 μm. The smaller size fraction (63–150 μm) was scanned for small species. Representative splits were obtained using a modified Otto microsplitter. The remaining sample was searched for rare species. All specimens from the sample split were picked, mounted on microslides as permanent record, and all species identified. Percent abundances of each species were calculated and recorded in Table 1. Common species are illustrated in Plates I–IV.

Biostratigraphy

Biostratigraphy and age control for the El Kef section in this study is based on planktic foraminifers (Smit, 1982; Keller, 1988). Nannofossils have also been studied in detail by Perch-Nielsen (1981 a, b) and Romein and Smit (1981) who considered El Kef as one of the most complete sections known to date. Based on El Kef and the Gredero (Caravaca, Spain) sections, Smit (1982) defined a new earliest Danian P0 Zone (*Guembelitria cretacea*). Based on analysis of closely spaced samples at El Kef the present author proposes a further subdivision of P0 as well as of the latest Maastrichtian *Abathomphalus mayaroensis* Zone (Keller, 1988). These zonal modifications lead to increased stratigraphic resolution for the Cretaceous–Tertiary boundary interval.

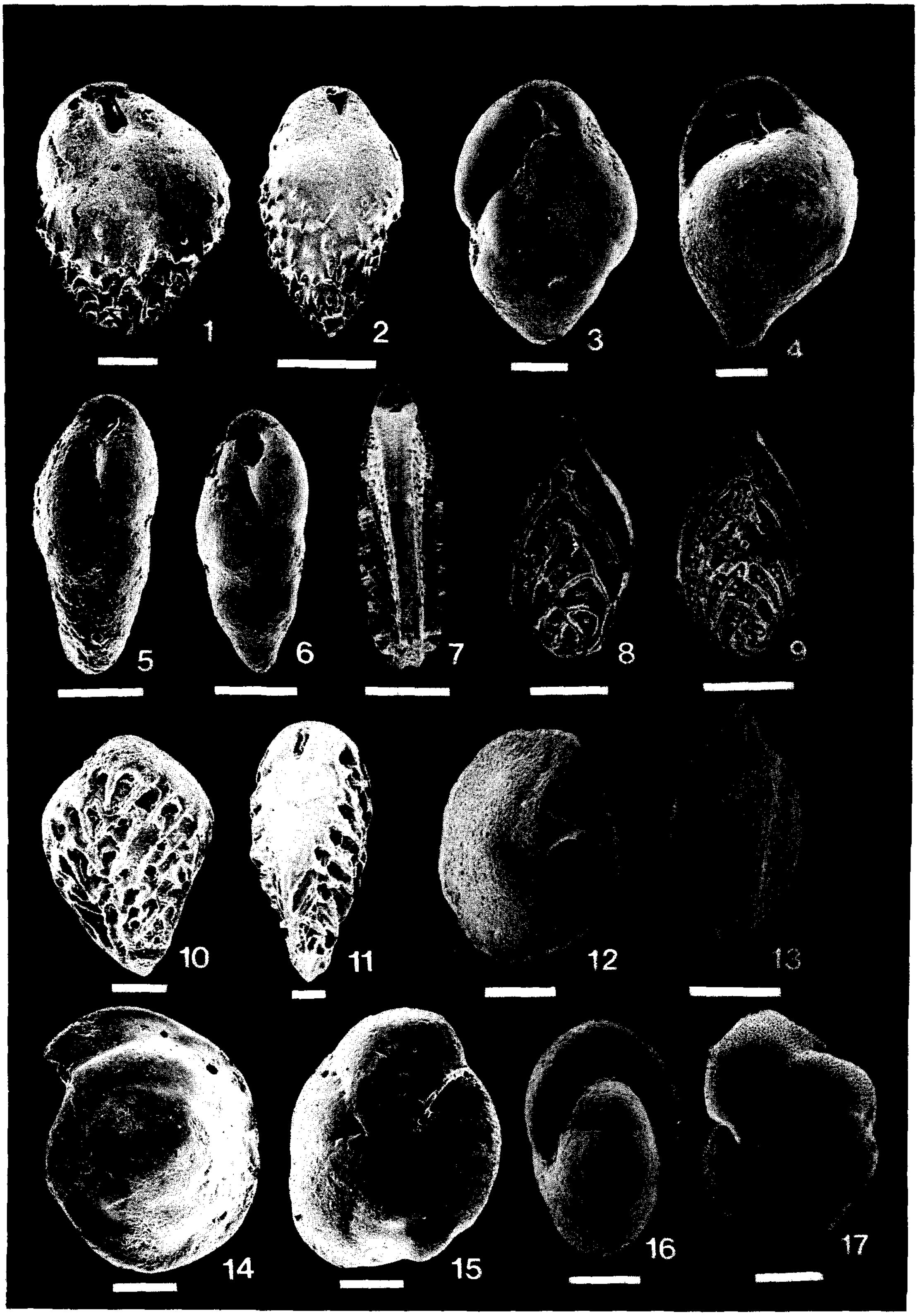
The 4 m of uppermost Maastrichtian sediment examined do not contain *Abathomphalus mayaroensis*, the index species of the latest Maastrichtian zone with the same name. Absence of this species in latest Maastrichtian sediments was earlier observed by Salaj (1980), and was also recently observed by this author in the Brazos River section of Texas and by Jones et al. (1987) in the Braggs section of Alabama. The frequently observed absence of *A. mayaroensis* from uppermost Cretaceous sediments indicates that this species disappeared prior to the K/T boundary at least in continental shelf regions. For this reason, a new zone *Pseudoguembelitria deformis* has been defined for the uppermost Maastrichtian sediments (Keller, 1988). *Pseudoguembelitria deformis* has been observed to range to the Cretaceous/Tertiary boundary. The base of this zone is defined by the last appearance of

TABLE I

Relative percent abundance of species in upper Cretaceous to lower Paleocene sediments at El Kef, Tunisia

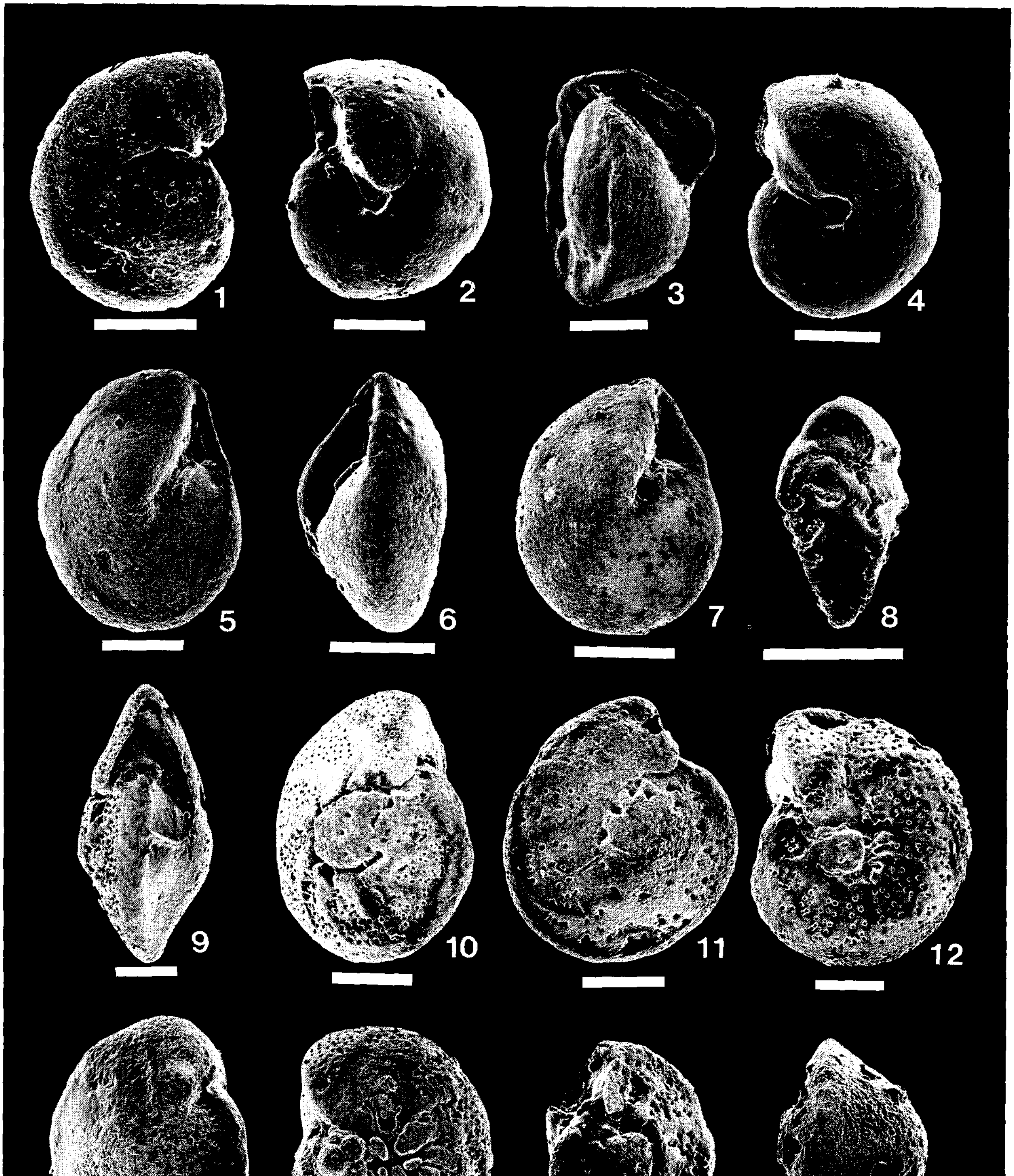
EL KEF, TUNISIA BENTHIC FORAMINIFERA size fraction >150 µm x = <2%	528 -450cm	529 -400cm	530 -350cm	531 -300cm	533 -200cm	535 -100cm	537 -60-70cm	539 -20-30cm	540 - 0-10cm	541 0-5cm	542 5-10cm	545 20cm	547 30cm	549 40cm	551 50cm	553 60cm	555 70cm	557 80cm	560 95cm	562 105cm	565 120cm	568 135cm	570 145cm	572 155cm	574 165cm	576 175cm	579 190cm	582 225cm	584 265cm	585 285cm	587 350cm	589 450cm	591 550cm	594 700cm
Alabamina midwayensis Brotzen												7	8	8	4	3	5	5	3	5	2	4	6	6	5	4	4	3	5	x	4	3		
Allomorphina trochoidea				x		x	x		x																									
Angulogerina cuneata Brotzen			x				2	x	x			x	x	x	x		x	x	x	x	2	x	x	2	x	x	x	x	x	x	x			x
Anomalinoides acuta (Plummer)	6	13	13	23	9	15	7	22	18	55	71	47	23	41	29	35	38	40	33	40	49	50	40	38	36	39	38	40	46	43	39	40	11	10
Anomalinoides praeacuta (Vasilenko)	x	x	x		x				5	2	x	6	8	12	10	11	9	10	6	8	4	2	3	8	5	5	5	6	4	3	4	3	x	5
Anomalinoides welleri (Plummer)		x	x	x	5	2	2	2	x	x																				x	8	5	6	2
Ammodiscus cretaceus (Reuss)															x		x	x				x								x		x		
Ammodiscus glabrata Cushman & Tarvis	x	x	x	x		x		x	x						x		x	x	x							x				x	x		x	
Ammodiscus lajollaensis Sliter											x	2	2	2	x	x	x	2	x	x	x	x	x	x	x	x	x	x	x	x	x			
Astacolus richteri (Brotzen)			x	x	x			x																										
Astacolus sp.	x	x						x	x	x	x										x			x										
Bolivinoides draco (Marsson)	x	x	x	x	x	2		6	7	x					x		x		2						x	x	x			x	x	x	x	x
Bolivina decurrens (Ehrenberg)					x		2		x	x	x			x	x	x			2	x	x		3	3	5	x	x		x		x		2	x
Bolivina incrassata Reuss	2		x	x	x	x	x	x	3	x		3	6	x	x	x	3	2	8	4	3	3	3	3	6	3	5	2	x	x	x	x	3	x
Bolivina midwayensis Cushman	x	x	x	3	3	x	2	3	x	x	x	x			2	3		x	x	x	x		2	x		2		x	x				x	3
Bulimina farafraensis Le Roy	x	x		x	x		x			x						x	x	x	3	2	2	x	7	5	4	4	14	10	x	6	4	3	5	5
Bulimina kugleri Cushman & Renz							x		x	2	2	x	3																					
Bulimina midwayensis Cushman & Parker	x		x					2	2	x																								
Bulimina pupoides D'Orbigny	x			x	x				x	4	x	3	5	x	x	x	x	x		4	x	2	x	x	x	2		x	x	x	x	x		x
Bulimina quadrata Plummer	x			x		x	x		x	3	9	2	2	2	x	2	x	x	2	x	x	x	x	x	x	2	x	x		x	x	x		
Bulimina trigonalis ten Dam							x				x																							
Buliminella carseyae (Plummer)	x	3	4	2	20	9	7	3	x	x												x	x		x		x		x					
Buliminella cushmani Sandidge	17	14	9	x	x	2	7	8	5	3	x																							
Buliminella sp.																		x							x		x	x	x					
Cassidulina globosa Hantken		x			x	x	x	3	x	x																								
Cibicides beadnelli Le Roy					3		x	x	x		x	2						x											2	x	3	x	12	7
Cibicides praecursorius (Schwager)			x		x	x	x			x													x						x	x				
Cibicidoides alleni (Plummer)												x	x																					
Cibicidoides succedens (Brotzen)																x		2																
Cibicidoides susanensis (Browning)												x	x		x	4	x	2	2	4	x	2	x	2	x	2	2	x	x	x				
Cribrostomoides trifolium (Egger)																x		x		x	x		x	x	x		x	x	x	x		x		
Coryphostoma plaitum (Carsey)	4	x	3	x	3	x	x	x	x																									
Dentalina basiplanata Cushman		x		x		3	2	x					x	x			x	x		2	x		2	3		3	2							
Dentalina colei Cushman & Dusenbury			x	x					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	2	x		x	x		x	x	
Dentalina gracilis (D'Orbigny)	2	3	3	3	x			2	4	x	x	2	x	x	2	3	3	2	2		x	2	x	x	x	4	x	2	x	x	x			2
Dentalina vistulae Pozaryska	x	3	x	x	x	3							6		3		6	2	2	4	4	x	x	x	2		x	x				x		
Dentalina sp.	x		x	2	2	3	3	2	x	3		5	8	5	2	4		2	x			x	4	3	3		x	4	2	x			x	
Dorothia bulleta (Carsey)		x		x																														
Dorothia oxycona (Reuss)	x	2	x	x	x	x		x	x	x								x	x	x				x						x	x	3		
Eponides lunatus (Brotzen)	x					x														x														
Fissurina oblonga Ruess			x										x											x										
Fissurina orbignyana Sequenza		x	x	x		x	x	x	x																									
Fursenkoina sp.																						x											3	14
Gavelinella lellingensis (Brotzen)	x	2	2	2	x	2	4	2	4																									
Gaudryina pyramidata Cushman	3	x	x	3	x	x	x	3	3	x																						4	x	
Globulina lacrima (Reuss)							x		x					x	2	x	x	x		x		x	x	x	x	x	x	x						
Glomospira charoides								x		x		x	x				x			x				x										
Guttalina subsphaerica (Berthelin)		x	x				x			x		x	x	x				x	x	x	x			x			x							
Gyroidina girardana (Reuss)	x	4	3	2	x	5	5	4	4	2				x																				
Gyroidina orbicularis D'Orbigny								x							x	x			x				x		x	x	x		x	x	x	2	7	
Gyroidina planulata Cushman & Renz	4	2	x	3	x	x	x		x												x													
Gyroidinoides quadrata martini Sliter	5	2	4	x	3	2	3	2	x																									
Gyroidina depressa	x		x	x	x		x	x																										
Gyroidinoides subangulata (Plummer)	2	x	3	4	3	2	4	3	2	x			x	2	7	3	3	6	2	x	x	x	x	x	x	x	x	x	x	x		x	4	
Gyroidinoides greatvalleyensis		x		3	x	x																												
Haplophragmoides desertorum Le Roy										x		x	x	2	x	x	x	x	3	x	x	x					x	x	x	x	x		x	
H. excavatus Cushman & Waters	x											x	x	x																				
H. famosus Takayanagi		x				x		x	x	x					x	x		x	3		x		x	x	x					x	x	x	x	
H. kirki Wickenden													x		x					x	x		x	x	x			x			x			
Lagena hispida Reuss	x	x			x	x	x	x	x					x	2		x	x		x	x		x		x	x						x		
Lagena sulcata (Walker & Jakob)				x	x		x		x					x					x				x			x	x	x	x		x		x	x
Lenticulina modesta (Bandy)	x			x	x	x	x	x	x				x	x	x	x	x			x			x	x			x	x	x	2				
Lenticulina muensteri (Roemer)	4	x	3	x	x	x	x	x	4	3	2	2	x	4	x	3	4	2	2	x	2	3	x	x	x	2	2	x	3	3	4	5	x	x
Lenticulina sp.	x					x		x				x	x	x	x		x	x	x	x			x	x	x	x			x					
Marginulina bulleta Reuss																x							x								x			
Marginulina curvatura Cushman			x	x	x										x																			
Nodosaria affinis Reuss	x	x	x	x	x	x			x	x						x			x	x	x		x											
Nadosaria aspera Reuss						x	x																											
Neoflabellina rugosa (D'Orbigny)				x	x																													
Neoflabellina suturalis (Cushman)	x		x	x	x	x	x	x	x																									
Nonionella africana Le Roy																																	2	2
Nonionella insecta (Schwager)				x					x																									
Nonionella ovata Brotzen																			x												x		x	
Oridorsalis umbonatus	3	2	2	x	3	6	x																									x		
Oolina apiculata Reuss	x	x	x	x	x	x	x	x	x			x	x			x		x	x		x	2		x	x	x	x	x	x	2	2	2	x	x
Oolina globulosa Reuss	x	x	x	x							x		x																					
Osangularia cordieriana (D'Orbigny)	5		x		x		2	x	x			x	x	2	x	2	x	3	x		6	4	5	3	2	2	3	4	9	8	3	5	8	2
Palmula primitiva Cushman	x	x	x	x	x		x																							x				
Parrella desertorum Le Roy					4																													
Pleurostomella paleocenica Cushman																								x							x			
Praebulimina reussi (Morron)	x	x	x	x	3	2	2	x	x	x	4	x	x	x	x	x	2	x	2	3	x	x	2	x	2	4	2	2	3	3	2	4	x	x
Praebulimina lajollaensis Sliter											x		4	x		x	2	x	x	2	3	2	x		x	x	x	x	x		2	x		
Pseudonodosaria obesa (Loeblich & Tappan)		x		x		x	x	x	x	x	x	x																						
Pullenia quinqueloba (Ruess)		x	x	x	x	x	x	x	x	x																						x		
Pyrulina apiculata (Marie)			x	x	x	x	x	x	x	x					x	x							x		x								x	
Quinqueloculina gussensis (Schwager)	x		5	x		x	2	x	x																									
Q. harisi Howe & Roberts	x	x	x	x				x																										
Q. stelligera Schlumberger								x	x																									
Ramulina pseudoaculeata (Olsson)													x			x			x	x				x		x								
Saracenaria navicula (D'Orbigny)	x	x	x	x	x	x			x	x																								
Saracenaria triangularis (D'Orbigny)	x	x					x		x																									
Siphogenerinoides eleganta (Plummer)																					x		x						x		x			
Spiroplectammina knebeli Le Roy	x	x	x					x																										
Stilostomella midwayensis (Cushman & Todd)			x	x	x		2		x	x		x	x																					
Tappanina selmensis (Cushman)																			4		x		x		2	x	x	x	x				15	12
Trifarina esnaensis Le Roy	8	8	7	10	4	6	8	4	4																									
Tristix excavata (Reuss)	x			x			x	x	x	x															x					x				
Tritaxia midwayensis (Cushman)	x							x																										
Trochammina globigeriniformis (Parker & Jones)																							x		x									
Uvigerina magfiensis Le Roy	x	x	x		x	x	2	x	x																									
Uvigerinella sp.																																	x	2
Valvulineria aegyptiaca Le Roy		2	3	x	x	2	x	3	2	x		x	2	3	2	3	x		2	x	x	3	x	x	2	2	3	2	2	2	3	3	5	
Nuttalides sp.																																		7
Unidentified	4	5	3	2	3	2	x	2	x	x	x	x	2	2	2	x	x	x	x	2	x	x	2	x	2	x	x	2	x	2	3	3	4	8
Total Number of specimens counted	262	215	281	312	444	240	242	319	450	276	206	218	294	301	341	250	294	466	259	191	435	257	359	340	252	256	306	295	323	296	262	217	201	295

PLATE I



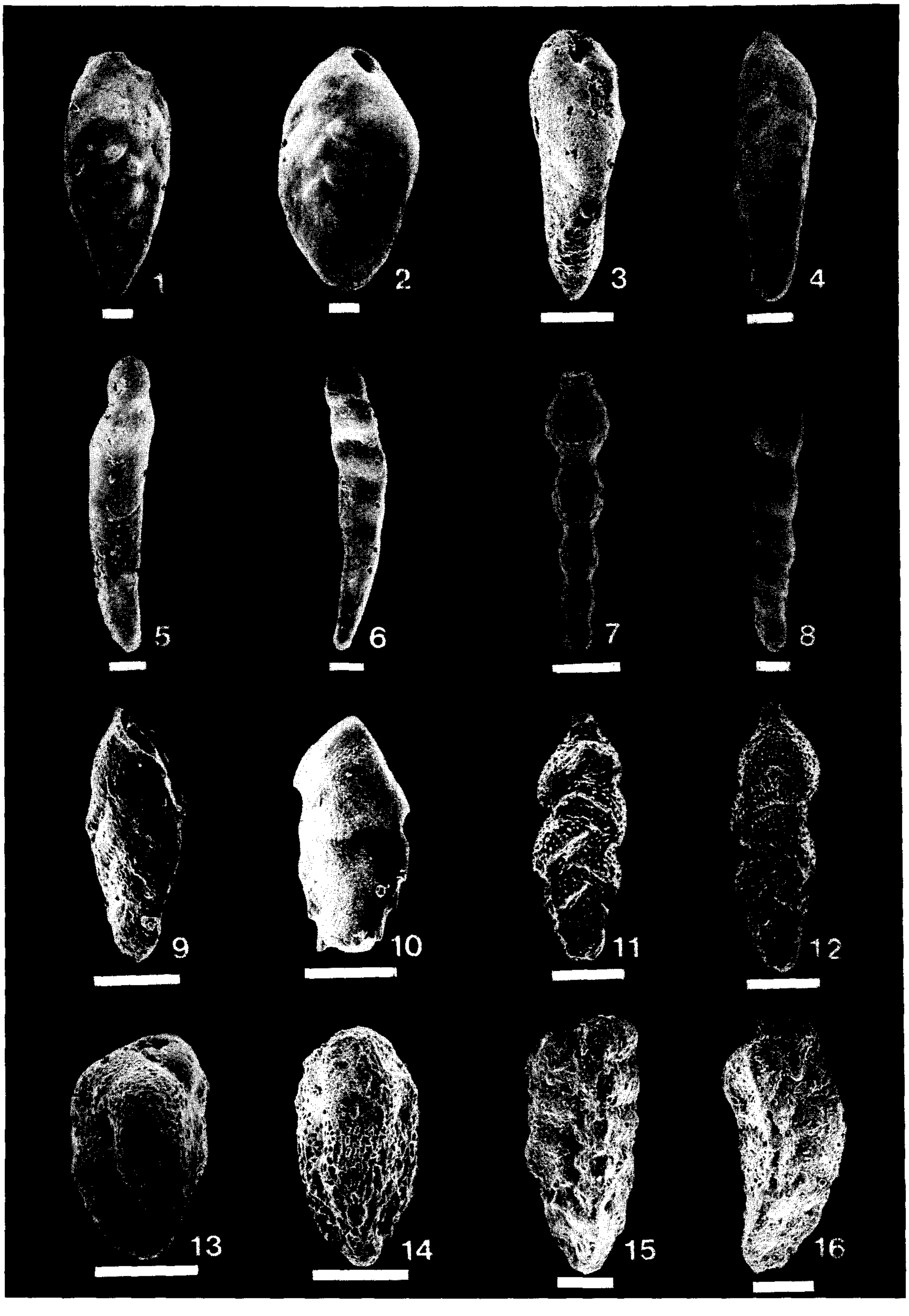
(for explanation see p. 161)

PLATE II



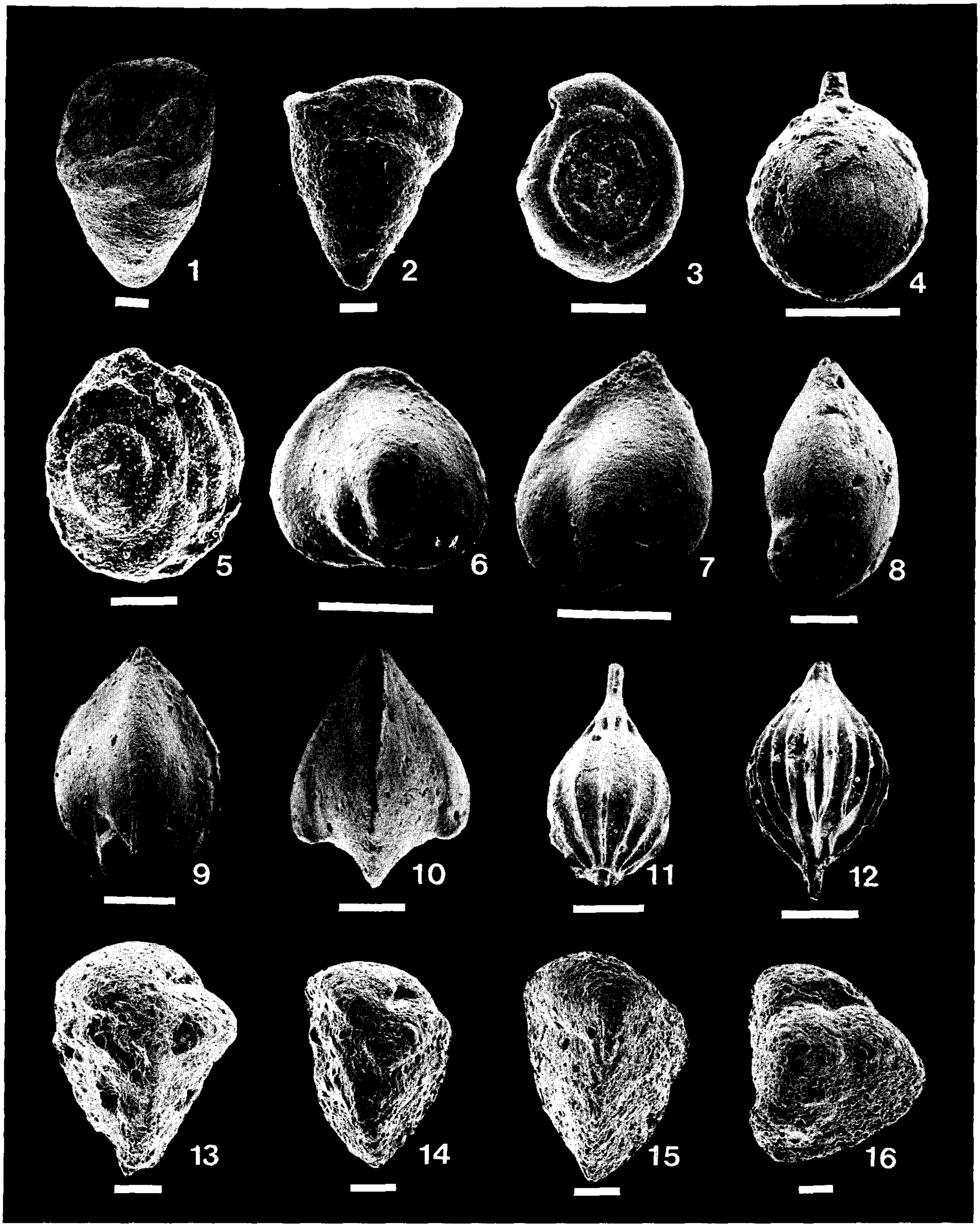
(for explanation see p. 161)

PLATE III



(for explanation see p. 161)

PLATE IV



(for explanation see p. 161)

A. mayaroensis and the top by the last appearance of *P. deformis* as well as all Cretaceous globotruncaniid species.

The Cretaceous–Tertiary boundary is defined sedimentologically by the base of the black clay layer overlying grey marls of Maastrichtian age. Geochemically the boundary is characterized by the 1–3 mm thick iron-rich

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PLATE I (see p. 157)

All species from uppermost Maastrichtian, *Pseudoguembelitria deformis* Zone Bar length represents 100 μm.
1, 2. *Bulimina midwayensis* Cushman and Parker, side views, sample 530.
3, 4. *Buliminella cushmani* Sandidge, side views, sample 528.
5, 6. *Buliminella carseyae* (Plummer), side views, sample 531.
7–9. *Neoflabellina rugosa* (d'Orbigny). 7, edgeview, 8, 9, side views, sample 531.
10, 11. *Bolivinoides draco draco* (Marsson). 10, side view. 11, edge view, sample 531.
12, 13. *Osangularia cordieriana* (d'Orbigny). 12, dorsal view. 13, edge views, sample 528.
14, 15. *Oridorsalis umbonatus* (Reuss). 14, spiral view. 15, umbilical view, samples 528, 530.
16, 17. *Pullenia quinqueloba* (Reuss). 16, apertural view. 17, side view, sample 529.

PLATE II (see p. 158)

Bar length represents 100 μm.
1–4. *Gyroidinoides subangulatus* (Plummer). 1, 2, *G. cf. subangulatus*; 1, spiral view; 2, umbilical view, sample 560, *Globigerina eugubina* Zone. 3, 4, *G. subangulatus* 8s; 3, edge view; 4, umbilical view, sample 531, *P. deformis* Zone.
5–7. *Alabamina midwayensis* Brotzen. 5, 7, umbilical views. 6, edge view, sample 572, *Globigerina eugubina* Zone.
8. *Tappanina selmensis* (Cushman), side view, sample 560, *Globigerina eugubina* Zone.
9–16. *Anomalinoides acuta* (Plummer). 9, 16, edge views. 10, 11, 13, 15, spiral views. 12, 14 umbilical views. Dominant species in earliest Tertiary samples 541–589, *G. cretacea* through *G. eugubina* Zones.

PLATE III (see p. 159)

Bar length represents 100 μm.
1, 2. *Bolivina incrassata gigantea* Wicker, side views. 1, sample 528, *P. deformis* Zone. 2, sample 572, *G. eugubina* Zone. Rare specimens, included in *B. incrassata* on Table I.
3, 4. *Bolivina incrassata* Reuss, side views, sample 539, *P. deformis* Zone.
5, 6. *Coryphostoma plaitum* (Carsey), side views, samples 531 and 539 respectively, *P. deformis* Zone.
7. *Stilostomella midwayensis* (Cushman and Todd), sample 537, *P. deformis* Zone.
8. *Dentalina basiplanata* Cushman, sample 562, *G. eugubina* Zone.
9, 10. *Bolivina decurrens* (Ehrenberg), side views, sample 537, *P. deformis* Zone.
11, 12. *Uvigerina maqfiensis* Le Roy, sample 539, *P. deformis* Zone.
13, 14. *Bulimina farafraensis* Le Roy, sample 560, *G. eugubina* Zone.
15, 16. *Trifarina esnaensis* Le Roy, sample 539, *P. deformis* Zone.

PLATE IV (see p. 160)

Bar length represents 100 μm.
1, 2. *Dorothia oxycona* (Reuss), sample 531, *P. deformis* Zone.
3. *Ammodiscus cretaceus* (Reuss), sample 531, *P. deformis* Zone.
4. *Oolina apiculata* Reuss, sample 572, *G. eugubina* Zone.
5. *Ammodiscus lajollaensis* Sliter, sample 549, *P. deformis* Zone.
6, 7 *Guttalina subsphaerica* (Berthelin). 6, ventral views, sample 529, *P. deformis* Zone. 7, side view, sample 557, Zone POb (*Globoconusa conusa* Zone).
8. *Saracenaria navicula* (d'Orbigny), side view, sample 529, *P. deformis* Zone.
9, 10. *Saracenaria triangularis* (d'Orbigny), dorsal views, sample 529, *P. deformis* Zone.
11, 12. *Lagena sulcata* (Walker & Jakob), sample 531, *P. deformis* Zone.
13–16. *Gaudryina pyramidata* Cushman. 13, 14, sample 539. 15, 16, sample 531, *P. deformis* Zone.

layer at the base of the black clay layer containing positive anomalies of iridium and siderophile elements (Kuslys and Krähenbühl, 1983), a negative excursion in carbon isotope ratios and a positive excursion in oxygen-18 isotope ratios (Keller and Lindinger, in prep.). Finally, the K/T boundary is defined by the extinction of all globotruncaniid species and the disappearance of most other Cretaceous planktic foraminifers.

The *Guembelitria cretacea* Zone or PO of Smit (1982) marks the lowermost Paleocene. Smit (1982) defined the interval of this zone from the K/T boundary to the first appearance of *Globigerina eugubina*. This zone is here further subdivided into POa and POb based on the first appearance of *Globoconusa conusa* which is the first Paleocene species to evolve after the K/T boundary event. These two zones encompass the boundary clay at El Kef with POa present between 0–25 cm and POb between 25–52 cm. The presence of POa and POb Subzones thus provides further stratigraphic control for completeness of the K/T boundary record. Subzone POb is succeeded by Pla (*Globigerina eugubina*) Zone and Plb (*Globigerina taurica*) Zone.

Benthic faunal analysis

Benthic faunas of the El Haria Formation at several localities southeast of El Kef have been described by Aubert and Berggren (1976). Many of the same species are present in the El Kef section although the faunal similarities decrease southward towards shallower and lagoonal environments. For instance, a maximum of twenty species occur in both El Kef and the northern Cherahill sections, but this number decreases to six in the southern Djebel Hamadi section. Species that occur in both the El Kef and Cherahill sections are: *Anomalinoides acuta, A. praecuta, A. welleri, Alabamina midwayensis, Cibicidoides susanaensis, C. succedens, Gyroidinoides subangulata, Glomospira charoides, Gavelinella lellingensis, Bulimina kugleri, B. quadrata, B. midwayensis, Ammodiscus glabratus, Tritaxia midwayensis, Dentalina colei, Nonionella insecta, Bolivina midwayensis, Gaudryina pyramidata, Pullenia quinqueloba* and *Palmula primitiva*.

Aubert and Berggren (1976) noted the cosmopolitan character of the Tunisian Paleocene faunas and their gross association with the Midway assemblages of the Gulf and Atlantic coastal Plain described by Plummer (1926). Even greater similarities between these faunas and El Kef are observed as well as with southern California faunas described by Sliter (1968). In addition, many species first described by Le Roy (1953) in the Esna shales of Egypt are present (e.g. *Bulimina farafraensis, Uvigerina maqfiensis, Spiroplectammina knebeli*).

Table I lists all species identified and their relative percent abundances. Figure 2 illustrates ranges of species that do not cross the Cretaceous–Tertiary boundary; 31 species (26 in Fig.2, additional 5 in Table I), or about 50% of the fauna, disappeared at or near this boundary. About 34 species ranged across and 11 species first appeared in the basal 50 cm of black clay after the boundary. In addition 5 species temporarily disappeared in the low carbonate deposits between the boundary and Zone Plb. These data indicate that a very significant proportion of the species was affected by changing environmental conditions near the K/T boundary. Many of the species however may have disappeared locally due to shallowing water conditions. Therefore, it is difficult to say how many species may have been adversely affected by a global K/T boundary event.

Figure 2 also illustrates that not all species disappeared simultaneously at the K/T boundary, but spread out over about 50 cm of sediment. Five species disappeared 20–30 cm below the boundary (sample 539); eleven species disappeared 0–10 cm below the boundary (sample 540) and seven species disappeared at the boundary (sample 541). In addition, one species disappeared 5–10 cm (sample 542) above the boundary and two species at about 20 cm (sample 545) above the boundary. This staggered disappearance indicates ecological selection below and after the K/T boundary

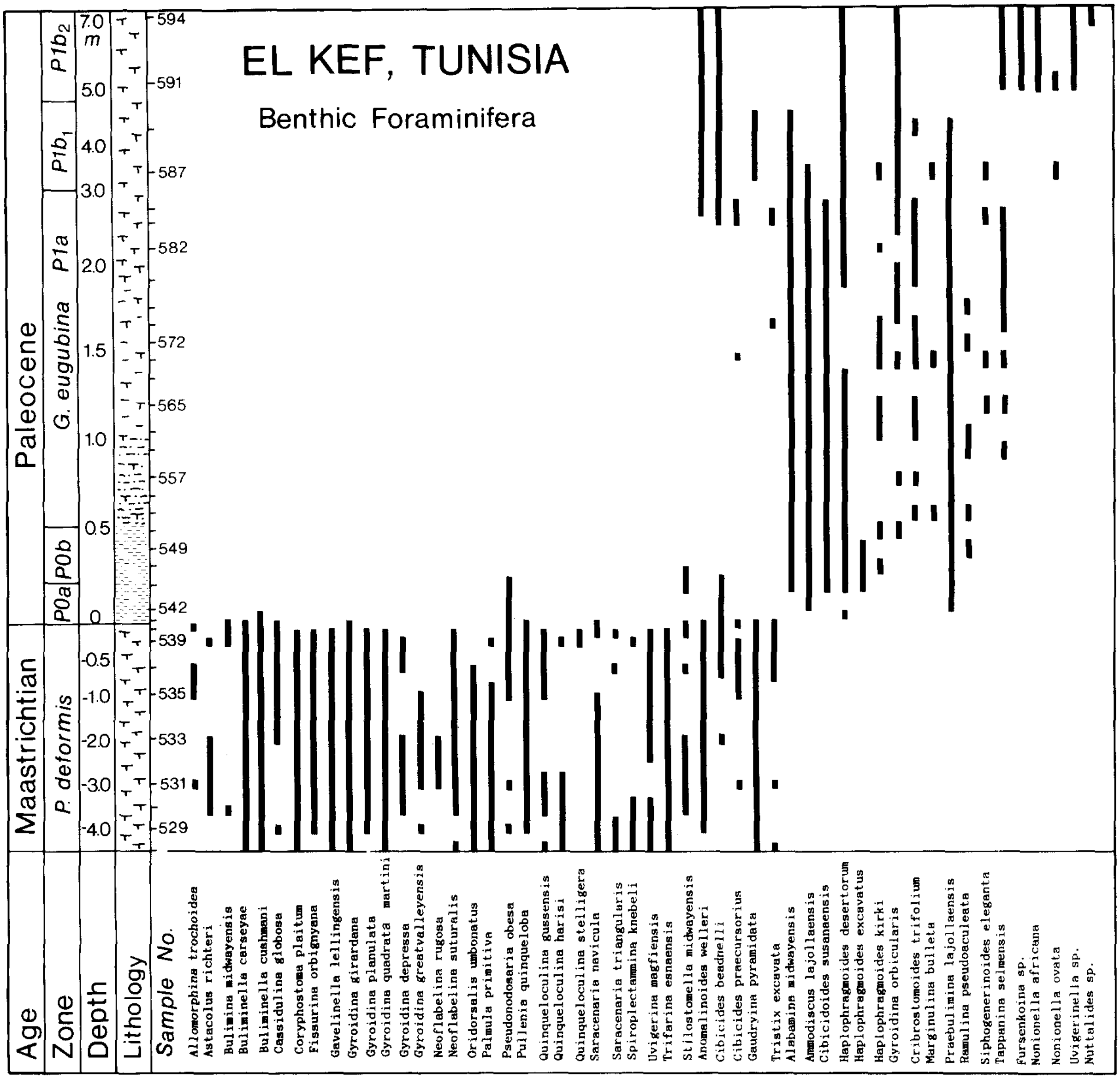


Fig.2. Range chart of selected species which appear affected by the Cretaceous/Tertiary boundary event. Planktic foraminiferal zonation from Keller (1988). Lithology discussed in text.

extinction event. A similarly prolonged extinction episode was observed among planktic foraminifera (Keller, 1988). This prolonged extinction episode is unlikely the result of a single K/T boundary bolide impact, but suggests adverse environmental conditions prior to the K/T boundary event as discussed below.

A 50% extinction rate does not appear unusual for benthic foraminifers at the K/T boundary. Beckmann et al. (1982) report about 60% of the species disappearing at the K/T boundary in a lower bathyal environment at Monte Giglio, Italy. In their survey of this boundary, Beckmann et al. (1982) also report that 32% of the species disappeared in Trinidad (Beckmann, unpublished), and 54% disappeared in the Tasman Sea (Webb, 1973). From these data it appears that both shallow and deeper water benthic foraminiferal faunas were severely affected by the Cretaceous/Tertiary boundary event. Some inferences regarding the possible cause of extinction in shallow shelf sequences can be drawn from quantitative analysis of El Kef faunas.

Figure 3 shows species diversity and the number of first and last appearances of species in each sample. Total species diversity is based on the number of species present plus the inferred presence of species (top two lines of histogram). A species was inferred to be present if the sample immediately above and below contained it. Figure 3 illustrates that species diversity during the late Maastrichtian was high averaging 58 species and sharply declined at the K/T boundary. The average diversity for the early Tertiary was about 37% lower. Applying the Shannon-Weaver index would show an even stronger species diversity change across the K/T boundary because the early Paleocene faunal assemblage is dominated by two species (*A. acuta* and *A. preacuta*, 50–60% of total assemblage). A slight increase in diversity occurred during Zone P1b, but does not show on this graph because a larger number of species disappeared at this time resulting in a net decrease in diversity.

Abundance fluctuations in the dominant

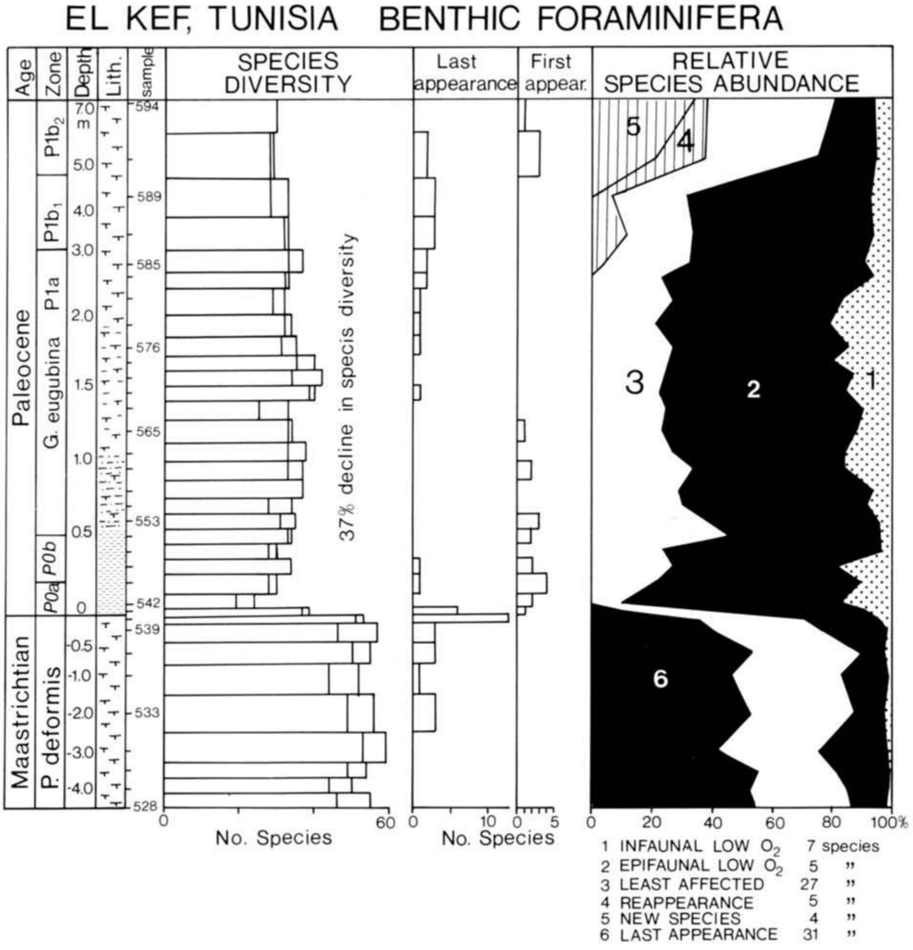


Fig.3. El Kef, Tunisia. Species diversity, first and last appearances of species and relative abundances of species grouped into: low oxygen infaunal or epifaunal, fauna disappearing at K/T boundary, fauna first appearing or reappearing after the boundary and fauna relatively unaffected by the K/T boundary event.

components of the benthic foraminiferal assemblages can yield clues to the type of environmental conditions prevailing at the K/T boundary. Relative percent abundances of the most common species are illustrated in Fig.4. The following species are common in the latest Maastrichtian, but absent in the earliest Tertiary at El Kef: *Buliminella cushmani, B. carseyae, Gaudryina pyramidata, Gavelinella lellingensis, Gyroidina girardana, G. planulata, G. quadrata martini, Oridorsalis umbonatus, Quinqueloculina gussensis, Trifarina esnaensis* (Fig.4). These species characterize an upper bathyal to outer shelf environment (Le Roy, 1953; Sliter, 1968, 1972). Their disappearance appears to have been caused primarily by a sea level regression.

A group of eleven species characterize the post K/T conditions up to P1b Zone. The most abundant of these species is *Anomalinoides acuta* and the related species *A. preacuta* which constitute about 50–60% of the total population (Fig.4). These two large-pored biconvex species are believed to have been epifaunal and tolerant of relatively low oxygen conditions. In addition to these species *Alabamina midwayensis, Osangularia cordieriana* and *Lenticulina muensteri* are also believed to be epifaunal species (Corliss, 1985, pers. comm., 1987). Their adaptation to living on the surface of the sediment where they scavenge for food may explain their success during the K/T boundary transition characterized by Zones P0a, b to P1a.

Other species common during the Cretaceous/Tertiary boundary transition are: *Praebulimina lajollaensis, P. reussi, Bulimina farafraensis, B. quadrata, B. pupoides, Bolivina*

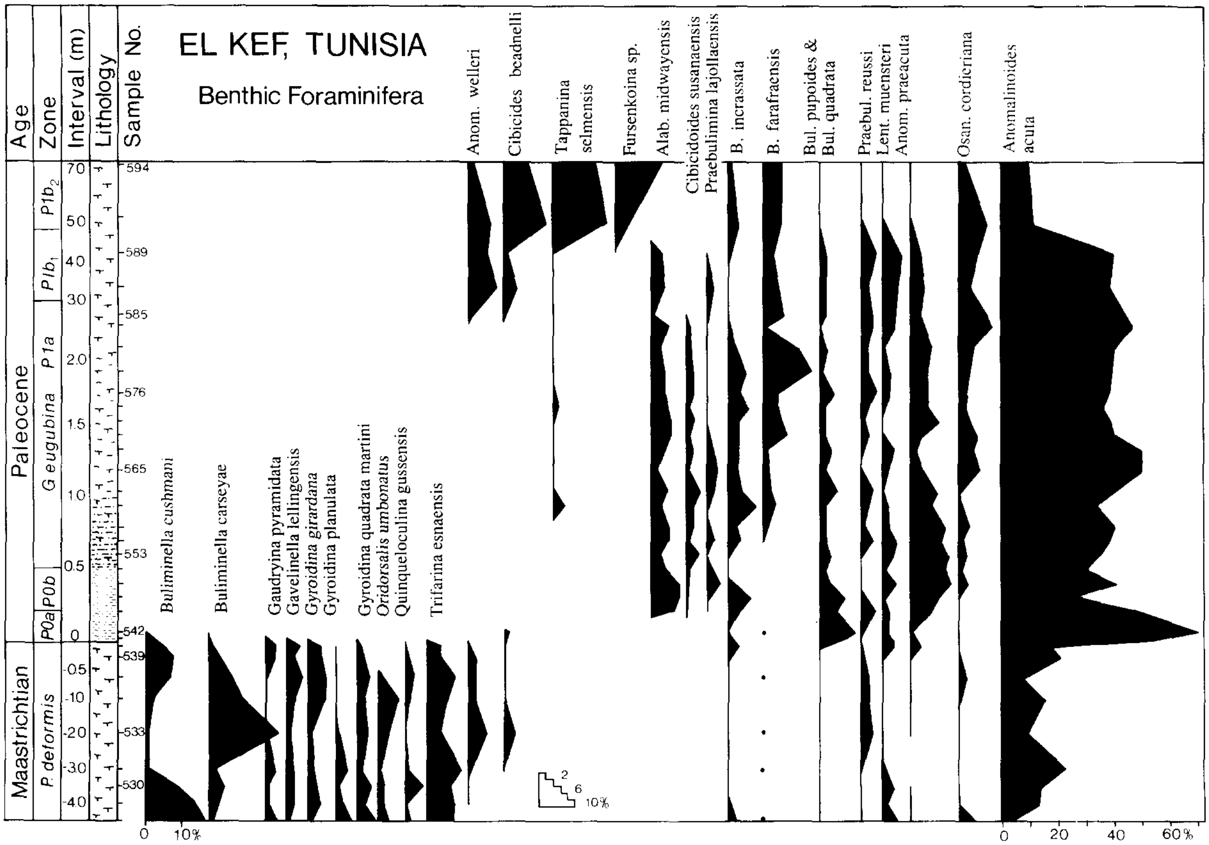


Fig.4. Relative percent abundance of common benthic foraminiferal species at El Kef, Tunisia. Dots indicate sporadic occurrence.

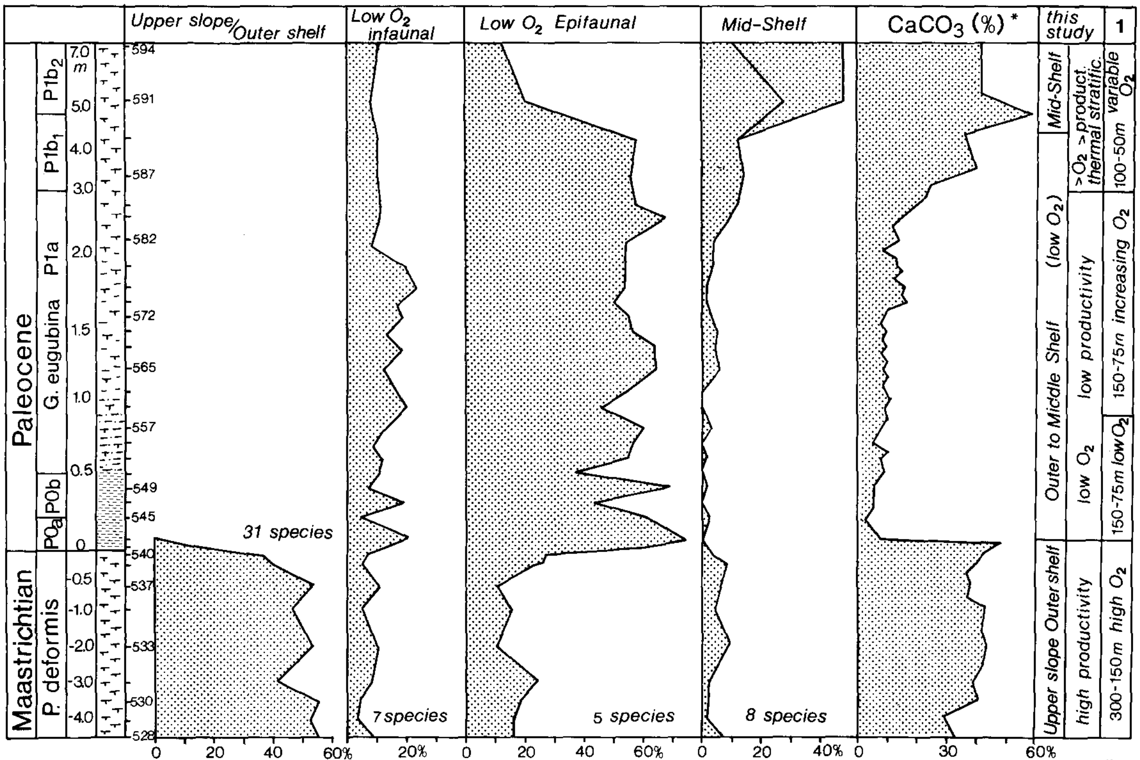
incrassata, (Figure 4). These genera and species are generally considered to be tolerant of low oxygen conditions (Sliter, 1968, 1972; Ingle, 1980) and are believed to be infaunal living in the upper 1–2 cm of the seafloor sediment (Corliss, 1985; pers. comm., 1987). Thus, the fauna characterizing the Cretaceous/Tertiary boundary transition appears to have been primarily low oxygen tolerant epifaunal and infaunal (Figure 5).

A general decrease in the abundance of the low oxygen fauna is apparent in the lower part of P1b Zone. The new species that thrive are: *Anomalinoides welleri, Cibicides beadnelli, Tappanina selmensis,* and *Fursenkoina* sp. (Figure 4). All of these species are present in the shallower southeastern Tunisian sections studied by Aubert and Berggren (1976) and many are also present in the Midway Formation of Texas (Plummer, 1926). At El Kef this faunal change is considered to represent somewhat shallower mid-shelf conditions with increasing oxygen content.

Paleoecology

The benthic foraminiferal assemblages of El Kef provide insight into the paleoecology of an upper slope to middle shelf environment during latest Cretaceous to early Tertiary time. In Fig.5 the species abundances shown in Fig.4 are grouped with respect to their inferred habitats. These groupings show a clear demarcation of specific paleoenvironments from which the following inferences can be drawn.

A total of 31 species disappeared near the K/T boundary (Table I) and are inferred to have lived in an upper slope to outer shelf



* Lindinger & Keller, in press
1 Peypouquet et al, 1986

Fig.5. Relative percent abundance of dominant species at El Kef, Tunisia, grouped by environmental associations. Percent carbonate data from Keller and Lindinger (in prep.). Paleodepth of deposition and oxygen levels from this study and from Peypouquet et al. (1986) based on ostracod data.

environment. Their disappearance in this region was probably largely caused by a sea-level regression, although thermohaline circulation changes may also have been responsible. Surviving and thriving species during the Cretaceous/Tertiary boundary transition (P0a, b to P1a) are primarily low oxygen tolerant infaunal (5 species) and epifaunal (5 species) species. After the K/T boundary transition, the five species which temporarily disappeared ("Lazarus" species, Jablonski, 1986) reappear along with several new species characteristic of mid-shelf depth (Midway Fauna, Plummer, 1926; Aubert and Berggren, 1976) (Figs.4 and 5). Percent carbonate in sediments reached pre-K/T boundary levels at this time indicating increased productivity (Fig.5).

In Fig.3 the relative population abundances of the faunal groups discussed above are plotted in cumulative percent abundance. This graph illustrates that about 50% of the individuals of the benthic foraminiferal population disappeared near the K/T boundary. They appear to have been replaced temporarily by the expansion of the low oxygen tolerant epifaunal and infaunal groups. These groups declined in Zone P1b with the appearance of a new shallow water fauna and the reappearance of species which temporarily vanished after the K/T boundary event. This suggests that more equitable environmental conditions returned at this time. About 1/3 of the individuals of the total benthic foraminiferal population appears to have been relatively unaffected by the K/T boundary transition.

Benthic foraminiferal data from El Kef thus suggests that sediment deposition during the uppermost Maastrichtian occurred in an upper slope to outer shelf environment. Further shallowing to middle shelf depth occurred by Zone P1b time. These interpretations are supported by paleobathymetric studies of ostracods at El Kef by Peypouquet et al. (1986). These authors reported a depth of about 400 m during the late Maastrichtian, shallowing to 150-300 m by K/T boundary time, and further shallowing to 50–100 m depth by Zone P1b to P1c time. A sea level regression during the late Maastrichtian was also reported by Ekdale and Bromley (1984) from Denmark based on sediment and trace fossil analyses. Shallowing during the late Maastrichtian was also observed in the Braggs section of Alabama (Jones et al., 1987) and Brazos River section of Texas (Keller, unpublished data). In fact, based on seismic stratigraphy a sea level regression during the late Maastrichtian appears to have been global (Haq et al., 1987) and may have adversely affected species diversity.

A clue to pre-K/T boundary adverse environmental conditions and species extinctions may also be found in the oxygen and carbon isotope analyses of El Kef (Keller and Lindinger, in prep.). These data indicate that paleoproductivity was relatively high for both benthic and planktic foraminifera during the latest Maastrichtian as implied by a carbonate content of about 45% and generally high carbon-13 values. Surface water temperature conditions were relatively stable but a negative shift in benthic oxygen-18 data of about 1.2‰ was observed. Thus, there is a convergent trend between surface and bottom water oxygen-18 values which may imply an influx of warm saline bottom water. A late Cretaceous ocean driven by thermohaline bottom circulation was earlier proposed by Brass et al. (1982). In their model warm saline water could have formed in low latitude marginal seas perhaps triggered by a sea level regression. Data from El Kef appear to support such a model. It is likely that the chemical consequences of the warm saline bottom water caused at least some of the species extinctions during the latest Maastrichtian.

The Cretaceous/Tertiary boundary is marked by a dramatic change from an oxygen-rich benthic fauna to a low oxygen tolerant fauna, a drop in the carbonate content and a major shift in the carbon and oxygen isotope data (Keller and Lindinger, in prep.). As noted earlier, productivity in surface waters dropped dramatically at the K/T boundary and remained low during the earliest Tertiary as inferred from faunal data as well as from carbonate and carbon-13 data. This drop apparently occurred nearly instantaneously in the 1–3 mm thin ferruginous clay layer at the base of the 50 cm black boundary clay. These geochemical data point towards a geologically instantaneous and catastrophic event that seems unrelated to the preceding environmental changes. Accelerated species extinctions at this time and a shift to a low oxygen tolerant epifaunal and infaunal assemblage appear to be a direct consequence of the K/T boundary event.

Paleoecological conditions on the sea floor during the early Tertiary (Zones PO to Pla) remained low in oxygen as indicated by both benthic foraminifera and ostracod assemblages (Peypouquet et al., 1986). This is also evident in deposition of 1 m of clay and 2 m of clayey shale with low carbonate content (5–10%) and abundant pyrite and manganese oxide indicating reducing conditions. Deposition at this time is likely to have occurred on a relatively stable platform of outer to middle shelf depth. Both bottom and surface water temperatures appear to have been cool but unstably fluctuating (Keller and Lindinger, in prep.). Benthic foraminiferal assemblages at this time are of low diversity and dominated by low oxygen tolerant epifaunal species. This group may have thrived at this time due to its ability to scavenge for scarce food sources on the ocean floor.

A change in paleoecological conditions is indicated about 3 m above the K/T boundary in the lower part of Zone Plb. This interval is marked by a decrease in the low O_2 tolerant fauna implying a return to more oxygenated bottom waters, and an increase in shallower shelf fauna indicating shallowing from an outer shelf to middle shelf depth. Peypouquet et al. (1986) estimated a depth of 50–100 m based on ostracod fauna in agreement with benthic data of this study. Ostracod faunas also indicate higher, although variable, oxygen conditions at this time (Fig.5). A major increase in carbonate to about 45% or pre-K/T boundary levels, coincides with these faunal changes and suggests higher paleoproductivity as also observed by a 1‰ carbon-13 shift (Keller and Lindinger, in prep.). Thus, more "normal" environmental conditions with oxygenated bottom waters and high paleoproductivity similar to pre-K/T boundary conditions began to reappear about 3 m above the K/T boundary event and after the *Globigerina eugubina* (Pla) Zone.

Discussion

Although the environmental effects of the Cretaceous–Tertiary boundary "event" can be inferred from benthic fauna, the ultimate cause remains elusive. Late Maastrichtian benthic foraminiferal assemblages indicate stressed conditions leading to species extinctions prior to the K/T boundary event. These stressed conditions may be explained by a thermohaline bottom circulation change perhaps triggered by a sea level drop and production of warm saline waters in low latitude marginal seas (Brass et al., 1982). Support for this interpretation is found in the 1.2‰ negative shift in oxygen-18 of benthic foraminifera (Keller and Lindinger, in prep.). Both benthic foraminiferal and oxygen isotope data thus imply adverse environmental conditions preceding and unrelated to the boundary event.

Geochemical data however, also indicate a sudden catastrophic environmental jolt at K/T boundary time which resulted in a crash in plankton productivity as indicated by a nearly 2‰ negative shift in carbon-13. A similar drop in surface productivity was observed earlier by Hsü and McKenzie (1985) and Arthur et al. (1987). Benthic foraminiferal species were less strongly affected by this event than planktic foraminifera (Keller, 1988). Moreover, it is difficult to judge which benthic species went extinct as a result of the K/T boundary event and which species extinctions resulted from the pre-boundary adverse ecological conditions.

After the K/T boundary event environmental conditions remained depressed for about 300,000 years (Zones PO through Plb) with low productivity and low oxygen bottom waters.

What caused this delayed recovery? Can a single extraterrestrial bolide impact explain this prolonged effect on both surface and bottom water communities? The effect of a dust cloud obscuring sunlight after a bolide impact is unlikely to affect the ecosystem for several hundred thousand years.

In summary, El Kef data suggest: (1) Long-term adverse environmental conditions beginning prior to the K/T boundary and ending near the P1a/P1b Zone boundary. (2) A major geologically instantaneous catastrophic jolt at K/T boundary time resulting in destruction of the ecosystem with surface water communities more severely affected than bottom water communities. (3) A prolonged recovery period of the ecosystem over at least 300,000 years.

Although geochemical data at the K/T boundary point towards an extraterrestrial impact (Alvarez et al., 1980), this hypothesis cannot explain the adverse environmental conditions prior to the K/T boundary, or the prolonged recovery period thereafter. El Kef data suggest that thermohaline circulation changes during the latest Maastrichtian caused at least some species extinctions. The long post-K/T boundary recovery period implies adverse environmental conditions fueled by a steady source such as a period of intense volcanism (Officer and Drake, 1985; McLean, 1985), or repeated shocks such as multiple impacts. However, no evidence of volcanism or multiple impacts was found in El Kef sediments. Further K/T boundary sections with a high sedimentation rate such as El Kef, Tunisia, need to be studied to investigate the sequence of events before, during and after the K/T boundary event.

Conclusions

Quantitative benthic foraminiferal analysis of the Cretaceous/Tertiary boundary sequence at El Kef shows that benthic faunas provide unique insights into the biotic and environmental conditions that prevailed during latest Cretaceous to earliest Tertiary time.

1. The present study suggests that a major sea-level regression culminated at the K/T boundary and a second regression occurred during the earliest Paleocene top P1a (*G. eugubina*) to base P1b Zones.
2. During the latest Cretaceous carbonate in the sediment was relatively high (45%), dropped to less than 10% at the K/T boundary and remained low through P0a, b to P1a Zones (3 m above the boundary). An increase in carbonate to pre K/T boundary values occurred above 3 m above the boundary in Zone P1b.
3. Both planktic and benthic foraminiferal productivity dropped dramatically at the K/T boundary and remained low during the first 3 m above the boundary (Zones P0a, b to P1a).
4. About 50% of the latest Cretaceous benthic species disappeared at the K/T boundary over a 50 cm interval beginning 20–30 cm below the boundary clay. These species are primarily of upper slope to outer shelf origin and may have disappeared partly as a result of the latest Cretaceous regression.
5. Average species diversity during the earliest Paleocene Zones P0a, b through P1a (*G. eugubina*) is 37% lower than during the latest Cretaceous. Species surviving and thriving during this interval are low O_2 tolerant epifaunal and infaunal species.
6. The decline in the low O_2 fauna at about 4 m above the K/T boundary is accompanied by the appearance of a shallower mid-shelf fauna and reappearance of about 5 ("Lazarus") species which were present in the latest Cretaceous fauna. This fauna represents higher oxygen levels and is accompanied by increased carbonate sedimentation.
7. The prolonged adverse environmental conditions indicated by benthic foraminifers and supported by oxygen and carbon isotopic data are difficult to explain by a single impact event at the K/T boundary, but may be explained by multiple mechanisms.

Acknowledgements

I would like to thank W. Sliter, E. Thomas and J. C. Ingle for review of this manuscript as well as for advice and consultation on species identifications, B. Corliss for discussions on species habitats, and M. Lindinger for permission to use unpublished carbonate data. W. R. Chi assisted in picking foraminiferal splits. I am grateful to K. Perch-Nielsen and T. Romein for providing samples from El Kef.

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