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# *Guembelitra*-dominated late Maastrichtian planktic foraminiferal assemblages mimic early Danian in central Egypt

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## Abstract

During the late Maastrichtian (66.8–65.5 Ma) the Asyut Basin in central Egypt experienced a breakdown of the surface to bottom gradient of the  $^{13}\text{C}/^{12}\text{C}$  ratio with planktic  $\delta^{13}\text{C}$  values 0.2–0.8‰ lighter than benthic values. Planktic foraminiferal species diversity was reduced by more than 50%, with assemblages dominated (60–90%) by the opportunistic blooms of the disaster species *Guembelitra cretacea*, which mimic the early Danian. The prolonged breakdown in productivity occurred during a time of tectonic activity and increased terrestrial runoff that may have resulted in highly eutrophic waters, coupled with a sea-level regression (65.5 Ma) that led to restricted circulation. Increased productivity during the short climate warming between 65.4 and 65.2 Ma is associated with increased species diversity, abundant rugoglobigerinids and common heterohelicids. At the end of the Maastrichtian, decreased productivity coincided with the K/T impact and mass extinction, followed by characteristically early Danian low diversity assemblages. The similarity of the late Maastrichtian and post-K/T impact *Guembelitra*-dominated assemblages reveals that the planktic foraminiferal response to the K/T catastrophe was not unique, but followed a predictable pattern of response to severe environmental perturbations.

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## 1. Introduction

During the early Maastrichtian a major sea-level transgression established open marine conditions throughout central Egypt, extending a shallow marginal sea to the south and west. Subsequent sea-level regressions caused widespread erosion, particularly in the marginal seas

to the south, coupled with local tectonic activity in the Western Desert (Hendriks et al., 1987; Schnack and Luger, 1998; Tantawy et al., 2001). On the stable shelf of the Asyut Basin, erosion was generally more limited, resulting in deposition and preservation of Egypt's most complete sedimentary sequences in the Eastern Desert (e.g. East Qena region, Luger, 1988; Luger et al., 1989; Duwi region, Tantawy, 1998; St. Paul, South Galala, Strougo et al., 1992; Faris, 1984). Among these sedimentary sequences, the Gebel Qreiya section studied for this report is among the very

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few localities where the planktic foraminiferal zone *Parvularugoglobberina eugubina* is present. During the late Maastrichtian to early Paleocene, Gebel Qreiya was located in the Asyut Basin (Fig. 1; Said, 1961, 1962) at about middle to outer shelf depths. This region was subject to sea-level fluctuations throughout the late Cretaceous and early Tertiary (Fig. 2; Hendriks et al., 1987; Luger and Groeschke, 1989; Klitzsch and Wycisk, 1987).

This report focuses on the late Maastrichtian and early Danian of the Gebel Qreiya section in order to: (1) evaluate the completeness of the section using a higher resolution biostratigraphic zonal scheme than has been previously applied, and (2) evaluate the paleoecology of central Egypt based on quantitative faunal analyses of planktic foraminifera and carbon isotopes of monospecific benthic and planktic foraminifera.

## 2. Lithology

The Gebel Qreiya section is located at the southern end of Wadi Qena, about 50 km north-east of Qena City and 18 km north of Km53 of the Qena–Safaga road (26°21' N, 33°01' E; Fig. 1). The Cretaceous–Tertiary boundary lies within the Dakhla Formation, which is widely distributed in central and southern Egypt, though with variable lithologies (e.g. Said, 1962; Abdel Razik, 1969, 1972; Soliman et al., 1986). The upper Maastrichtian consists of monotonous gray shales containing *Pecten farafraensis* casts that decrease upsection. At about 1.8 m below the K/T boundary, shales grade into marly shales devoid of macrofossils. About 10 cm below the K/T boundary the marly shales are truncated by an undulating erosional surface, which also truncates burrows (Fig. 2). The 10-cm-thick layer above this erosional surface consists of burrowed marly gray shale with small macrofossils (bivalves, gastropods). This macrofossil-rich layer is truncated by an undulating erosional surface. A thin red layer and thick dark shale overlies this erosional surface and marks the K/T boundary. Above the boundary, basal Danian sediments consist of fissile dark gray shales (50 cm), followed by gray marly shale (~2 m) and gray shale (Fig. 2). Lithological changes,

erosional surfaces, truncated burrows, and macrofossil as well as microfossil assemblages indicate that deposition occurred in a shallow marginal sea influenced by sea-level changes through the late Maastrichtian and early Danian (Fig. 2).

## 3. Methods

For foraminiferal studies samples were processed following the standard method of Keller et al. (1995). Planktic foraminifera are generally abundant and well preserved, except for some intervals of carbonate dissolution. The strongest dissolution is observed in the Danian zone Plc(2) (samples 72–86) where nearly all planktic foraminifera are dissolved. Dissolution effects in the lower part of zone Plc(1) are apparent by the abundance of broken specimens and thin test walls. No dissolution effects are apparent in the late Maastrichtian sediments, though pyrite is present (samples 34–39), suggesting low oxygen conditions.

Quantitative population analysis is based on the >63- $\mu\text{m}$  and >150- $\mu\text{m}$  size fractions in order to evaluate both small and large species populations. The larger size fraction favors late Cretaceous large tropical and subtropical species, whereas the smaller size fraction favors small Cretaceous species (heterohelicids, guembelitrads, globigerinellids, globotruncanellids) and all early Danian species. (There are no Danian species >150  $\mu\text{m}$  and very few are >100  $\mu\text{m}$ .) For each sample and each size fraction, about 300 specimens were picked from a representative sample split, mounted on cardboard slides for a permanent record and identified. Species richness evaluation is based on the presence of the total number of species in each sample from both size fractions, as well as rare species (labeled 'x' in Tables 1–3) detected in a search of the uncounted residue of each sample. Species identification follows standard taxonomic concepts (Robaszynski et al., 1983–1984; Caron, 1985; Nederbragt, 1991, 1998; Olsson et al., 1999). Common planktic foraminiferal species are illustrated in Plates I–VI, and quantitative species census data in Tables 1–3.

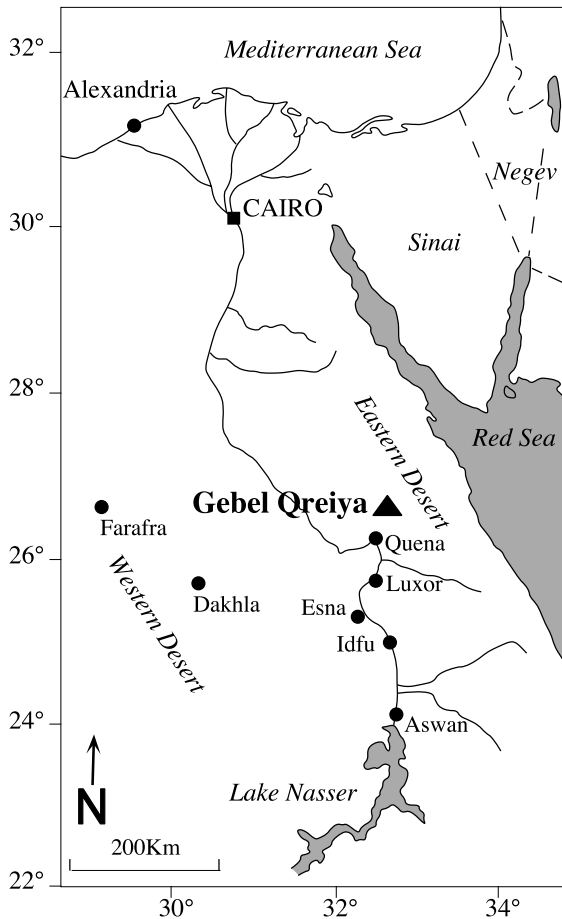


Fig. 1. Location of the Gebel Qreiya section in the Asyut Basin of central Egypt.

Stable isotope analyses were conducted on the benthic foraminifer *Cibicoides pseudoacutus* and the planktic foraminifer *Rugoglobigerina rugosa* from the size fraction 150–250  $\mu\text{m}$ . For selected early Danian intervals *Guembeltria cretacea*, *Woodringina hornerstownensis*, *Subbotina triloculinoides* and *Globanomalina pentagona* were also analyzed. All analyses were conducted at the laboratory of the University of Bern, Switzerland, using a VG Prism II mass spectrometer equipped with a common acid bath. The results are reported relative to the Vienna PeeDee Belemnite standard reference material with a standard error of 0.1‰ for oxygen and 0.05‰ for carbon.

#### 4. Biostratigraphy

The Gebel Qreiya section of the Asyut Basin is Egypt's most complete late Maastrichtian to early Danian sequence known to date, and also contains relatively well-preserved and abundant planktic foraminifera. To evaluate the nature and continuity of the sedimentary record, the biostratigraphy is evaluated here based on the Cretaceous foraminiferal (CF) zonal scheme by Li and Keller (1998a,b), which replaces the *Abathomphalus mayaroensis* zone with four zones and hence provides much improved age control for the late Maastrichtian (Fig. 2). Age estimates for the late Maastrichtian biozones are based on foraminiferal datum events of DSDP Site 525 tied to the paleomagnetic stratigraphy of the same core. Age correlations were also made with Tunisian sections based on biostratigraphic correlation and event stratigraphy, including sea-level changes and stable isotope stratigraphy (Li and Keller, 1998c; Li et al., 1999). Ages for these Maastrichtian and Danian datum events and biozones are broadly valid for the eastern Tethys region, including Egypt.

Age estimates for the Danian biozones are from Berggren et al. (1995). Correlation of the foraminiferal zonal scheme of Keller et al. (1995) to that of Berggren et al. (1995) is shown in Fig. 2, though this correlation is tentative due to their reported later first occurrences of the index species *Subbotina triloculinoides* and *Parasubbotina pseudobulloides*. In my experience analyzing various small (< 63  $\mu\text{m}$ , 63–100  $\mu\text{m}$ ) and larger (100–150  $\mu\text{m}$ , > 150  $\mu\text{m}$ ) size fractions, the delayed first occurrences of these species noted by Berggren et al. (1995) correspond to the first appearances of the larger (> 100  $\mu\text{m}$ ) morphotypes. In the smaller size fraction (< 100  $\mu\text{m}$ ) these species are present earlier, within the upper part of the *Parvularugoglobigerina eugubina* (Pla) zone (Fig. 2).

In this study, quantitative species analysis as well as first and last appearances of species are used to obtain biostratigraphic age control. Abrupt changes in assemblage composition may reflect an incomplete sedimentary record, or rapid environmental changes. The presence of hiatuses can be determined based on biostratigraphy and

Planktic Foraminiferal Zones			Gebel Qreiya		Lithology	Sea Level		
	Berggren et al. 1995	Li and Keller, 1998a Keller et al. 1995	Datum Events	Age m.y.	This Study	This Study	Based on lithology and biostratigraphy	
Early Danian	P1c	P1d	⊥ <i>P. trinidadensis</i>	62.2		gray shale		
		P1c(2)	⊥ <i>P. inconstans</i>	63.0		marly shale		
	P1b	P1c(1)		64.5	Hiatus?			
		P1b	⊥ <i>P. varianta</i> <i>S. triloc. large</i> <i>P. eugubina</i>	64.7	Hiatus			
	Pα	P1a(2)	⊥ <i>P. longiapertura</i> <i>S. triloc. S.pseudo.</i>	64.97	Hiatus			marly shale
		P1a(1)	⊥ <i>P. eugubina</i> <i>P. longiapertura</i>	65.0	Hiatus			dark shale, red layer erosional surfaces truncated burrows small macrofossils
Late Maastrichtian	A. mayaroensis	PO	⊥ <i>P. hantkeninoides</i> & extinction of tropical species	65.0		marly shale		
		Plummerita hantkeninoides CF1	⊥ <i>P. hantkeninoides</i>	65.3	Hiatus			
		<i>P. palpebra</i> CF2	⊥ <i>G. gansseri</i>	65.45 65.58				
		<i>P. hariaensis</i> CF3	⊥ <i>P. hariaensis</i>	66.83		gray shale rare macrofossils <i>Pecten farafraensis</i>		

Fig. 2. Planktic foraminiferal biozonation, datum events and lithology of the Gebel Qreiya section. Lithological changes, undulating erosional surfaces, macrofossils and microfossil assemblages in the Gebel Qreiya section indicate an interrupted sediment record and numerous hiatuses or condensed intervals probably as a result of sea-level fluctuations.

lithological observations (e.g. erosional surfaces, hardgrounds, concentrations of macrofossils, wood, truncated burrows, increased terrigenous transport).

## 5. Late Maastrichtian

### 5.1. Zone CF3

Zone CF3 defines the interval from the first appearance of *Pseudoguembelina hariaensis* to the last appearance of *Gansserina gansseri* (66.83–65.45 Ma) and is equivalent to the upper two thirds of the *Micula murus* zone. At Gebel Qreiya, the lower 7.5 m of the section analyzed mark zone CF3 as indicated by the co-occurrence of *G. gansseri* and *P. hariaensis*. *Micula murus* is present in this interval and suggests that the lower part of zone CF3, which corresponds to the upper

*Lithraphidites quadratus* zone, was not recovered (Tantawy, in press). Among small planktic foraminifera (> 63 µm) zone CF3 is dominated by alternating abundances of *Guembelitra cretacea* and *Heterohelix navarroensis*, whereas the larger species group is dominated by *Heterohelix globulosa* and *Laeterohelix labellosa* (Figs. 3 and 4; Plate III).

### 5.2. Zone CF2

Zone CF2 marks the interval from the last appearance of *Gansserina gansseri* to the first appearance of *Plummerita hantkeninoides* and spans about 150 000 years (65.45–65.30 Ma; Fig. 2; Plate II). At Gebel Qreiya this short zone may be missing or very condensed, as indicated by the juxtaposition of *G. gansseri* and *P. hantkeninoides* at 1.8 m below the K/T boundary. Various other species mark a hiatus or condensed interval

Table 1

Relative percent abundances of planktic foraminifera in the late Maastrichtian >150- $\mu$ m size fraction at Gebel Qreiya, central Egypt ( $x < 1\%$ )

Biozone	CF3												CF1 ( <i>P. hantkeninoides</i> )								Pla				
	42	41	40	39	38	37	36	35	34	33	32	31	30	28	26	24	22	20	18	16	14	12	11	10	9
Sample number	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	7.6	7.8	8	8.2	8.4	8.6	8.8	9	9.2	9.4	9.5	9.6	9.7
<i>Globigerinella aspera</i>	x	1	x	1	1	2	2	x	9	0	0	1	x	0	0	x	0	x	x	1	3	x			
<i>G. yaucoensis</i>		0	0		1		0	0									0	0	0	x	0	0			
<i>Globotruncanella minuta</i>			x	0	1					x									x			x			
<i>G. petaloidea</i>	2	2	1		1	x		2	3			1			x	x	x	x	x	1	x	2			
<i>G. subcarinatus</i>			0			0			0						0										
<i>Gansserina gansseri</i>	x	x		x		x	x			x	1	x	x												
<i>Globotruncana aegyptiaca</i>	1	x	x	1		x	1			x	x			1	x	x	x	x	x	x		x	(1)		
<i>G. duwi</i>	2	2	1		3					1	2			1	x	0	x	x	0	0		x			
<i>G. dupeublei</i>		x	x	2	x	x	1			2			x	x		x	0	0	0			0			
<i>G. esnehensis</i>	x	1	1	1	3	3	2	x	1	x	3	x	x	x	x	x	x	x	x	x	x	x			
<i>G. insignis</i>							x			x	x					x	x								
<i>G. rosetta</i>																x	x	x		x		x			
<i>Globotruncanita conica</i>					x																	x			
<i>G. pettersi</i>	x	x								1	1	x	x	x	x	x	x	x		x		x			
<i>G. stuarti</i>	x											x	x	x	x	x			x						
<i>Kassabiana pseudocalcarata</i>										x			x												
<i>Hedbergella holmdelensis</i>							x		x																
<i>H. monmouthensis</i>	x	x	x	x	x	2	x	1	x	0				0	1	0	0	0	0	0	0	0			
<i>Plummerita hantkeninoides</i>													5	7	13	6	12	14	6	3	7	1	(1)	(3)	
<i>Rugoglobigerina hexacamerata</i>	x	1	x	1	x	x	2	x	1	x	1	1	1	x	x	x	1	1	x	x	x	2	(1)	(2)	
<i>R. macrocephala</i>	6	7	5	2	8	5	1	3	5	4	x	2	3	1	5	11	1	5	2	6	6	5	(2)	(2)	
<i>R. reicheli</i>													2	4	8	5	6	3	2	x	1	2	(2)		
<i>R. rugosa</i>	7	9	13	5	5	13	1	4	4	3	1	x	3	5	13	12	8	14	9	13	13	8	(6)	(2)	(4)
<i>R. scotti</i>	4	6	4	4	x	1	3	24	6	4	1	x	2	2	x	2	1	2	x	1	x	1	(1)		
<i>Heterohelix globulosa</i>	26	26	26	30	36	21	22	38	36	15	16	33	27	30	29	18	22	21	23	29	18	23	(1)	(6)	(3)
<i>H. dentata</i>	1	1	3	1	x	1	x	x	x	3	4	5	17	11	3	8	11	4	16	4	10	8	(2)		
<i>Laeterohelix (H.) labellosa</i>	7	13	11	14	16	14	10	5	10	26	21	15	3	5	5	10	7	7	8	8	7	6	(1)	(2)	
<i>H. planata</i>	1	2	x	0		2	4	3			x			x	6	5	x	4	2	5	1	10			
<i>H. navarroensis</i>	3	4	3	2	2	2	3	x	x	x	x	x	x	x	x	2	0	0	0	0	x	x	(1)		
<i>H. punctulata</i>	3	3	4	8	3	4	1	6	1	3	6	3	3	x	2	1			0	4	0	x			
<i>H. d. punctulata</i>	3	3	x	4	1	1	2	0		x	14	14	11	13	3	8	8	8	13	10	14	11	(2)	(1)	(3)
<i>H. striata</i>	7	2	2	x	x	x	x	x	1	4	7		x	x		6	5		x						
<i>Pseudoguembelina hariaensis</i>	x	x							x	x	0		x	x	x	0	x	0	x	0			(1)		
<i>P. costulata</i>	7	3	6	4	3	2	6	x	4	7	8	6	9	5	5	5	6	2	3	8	7	4	(2)	(3)	
<i>P. kempensis</i>		x			x					1		1				0	x	1	0	1	1				
<i>P. palpebra</i>	1	x	x							x		2	x	x			1		2	x	1				
<i>Pseudotextularia elegans</i>	5	3	7	5	4	11	9	4	3	9	6	4	x	2	x	x	x	1	2	3	1	x	(2)		
<i>P. nuttalli</i>	2	2	1	5	4	2	1	5	1	2	1	x	2	1	2	x	1	1	2	x	2	x	(2)		
<i>Planoglobulina carseyae</i>	10	8	6	10	4	11	22	6	17	8	4	11	4	5	2	3	3	4	4	1	5	8	(1)	(1)	
<i>P. brazoensis</i>										x							x		x	x		x			
<i>Racemiguembelina powelli</i>										x						0	x								
<i>Guembelitra cretacea</i>	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	1			
Total counted (>150 $\mu$ m)	292	312	274	98	167	169	99	156	91	262	158	203	272	296	283	249	275	283	350	311	255	277	18	24	19
Species richness	27	29	28	24	26	25	27	22	22	31	24	22	25	30	30	32	33	29	33	31	26	30			

Numbers in parenthesis are not in percentages and generally reflect reworked specimens.

Species that are only present in the <63- $\mu$ m size fraction are indicated by 0.

Table 2

Relative percent abundances of planktic foraminifera in the late Maastrichtian >63- $\mu\text{m}$  size fraction at Gebel Qreiya, central Egypt ( $x < 1\%$ )

Biozone	CF3												CF1 ( <i>P. hantkeninoides</i> )									
	Sample number	42	41	40	39	38*	37*	36*	35	34	33	32*	31	30	28	26	24	22	20	18	16	14
Sample depth (m)	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	7.6	7.8	8	8.2	8.4	8.6	8.8	9	9.2	9.4
<i>Globigerinella aspera</i>	x	1	x	14	4	10	9	x	2	3	1	x	x	x	x	x	x	x	x	1	1	x
<i>G. yaucoensis</i>		x	x		4		x	x									x	2	1	x	1	1
<i>Globotruncanella minuta</i>				x	x					x									x			x
<i>G. petaloidea</i>	x	x	1		2	x		x	x			x			x	x	x	x	x	x	x	x
<i>G. subcarinatus</i>			1			1			x						x							x
<i>Globotruncana aegyptiaca</i>		x	x	x			x			x	x			x	x	x	x	x	x	x		x
<i>G. duwi</i>					x					x	x	x		x	x		x	x	x			x
<i>G. dupeublei</i>				x	x	x	x			x			x	x		x						
<i>G. esnehensis</i>				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>G. insignis</i>							x			x	x	x		x		x						
<i>G. rosetta</i>															x	x	x					x
<i>Globotruncanita conica</i>					x																	x
<i>G. pettersi</i>				x		x	x			x	x	x	x	x	x	x	x	x	x		x	x
<i>G. stuarti</i>												x	x	x	x	x			x			
<i>K. pseudocalcarata</i>										x			x									
<i>Hedbergell holmdelensis</i>							1		x													
<i>H. monmouthensis</i>	x	2	2	2	2	3	x	x	x	x				4	2	2	3	10	6	6	3	2
<i>Plummerita hantkeninoides</i>													2	2	1	3	5	x	3	1	x	x
<i>Rugoglobigerina hexacamerata</i>			x	x	x	x	x	x	1	x	x	x	x	x	x	2	x	x	x	x	x	x
<i>R. macrocephala</i>	1	1	2	x	17	12	1	x	x	1	x	x	x	x	2	x	1	x	x	1	x	1
<i>R. reicheli</i>														2	2	1	1	x	x	x	x	
<i>R. rugosa</i>	x	x	1	3	2	x	1	x	1	x	x	x	x	4	1	2	3	x	2	x	x	
<i>R. scotti</i>	x		1	x	x	x	x	x	1	x	x	x	x	x	x	x	2	x	x	x	x	x
<i>Heterohelix globulosa</i>	4	6	9	x	x	x	x	x	4	20	x	5	16	12	9	14	21	16	30	9	8	7
<i>H. dentata</i>	x	1	2	x	1	2	x	x	1	x	x	4	x	4	1	6	3	5	x	8	x	
<i>Laeterohelix (H.) labellosa</i>		x	3	x	x	x	x	1	10	x	x	x	x	4	x	11	3	x	x	x	1	
<i>H. planata</i>	x	1	4	x		4	7	x			x			2	x	1	2	1	3	1	x	x
<i>H. navarroensis</i>	16	19	17	37	63	55	72	13	11	12	x	x	5	5	3	6	12	14	22	23	7	15
<i>H. punctulata</i>	x	x	2	x	x	x	x	x	x	x	2	x	x	x	x				1	x	1	
<i>H. cf. punctulata</i>		x	1	x	x	x	x			x	x	9	1	1	x	x	3	x	5	2	2	x
<i>H. striata</i>		x		x	x	x	x	x	x	x					x		x	x				
<i>Pseudoguembelina hariaensis</i>									x	x	x			x	x	x			x			
<i>P. costulata</i>	2	3	2	x	x	x	x	1	13	x	x	3	6	x	3	7	3	5	1	3	2	
<i>P. kempensis</i>		x			x		x			x		x			1	1		1	x	x		
<i>P. palpebra</i>									x		x	x					x		x	x		
<i>Pseudotextularia elegans</i>	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Pseudotextularia nuttalli</i>				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Planoglobulina carseyae</i>	2	x	1	x	x	x	x	x	x	x	x	5	1	x	1	x	1	3	1	x	2	x
<i>Planoglobulina brazoensis</i>										x							x		x			x
<i>Racemiguembelina powelli</i>										x							x					
<i>Guembelitra cretacea</i>	66	65	51	43	2	8	7	85	80	32	97	70	64	66	64	62	20	39	11	39	47	55
<i>Guembelitra danica</i>																			x			
<i>G. trifolia</i>													x	x	2	x	x	2	x	10	5	7
Total counted (> 63 $\mu\text{m}$ )	220	266	201	140	75	83	69	187	208	182	236	187	253	256	283	313	329	277	332	282	231	282

\*Fine fraction pyritized and dissolved.



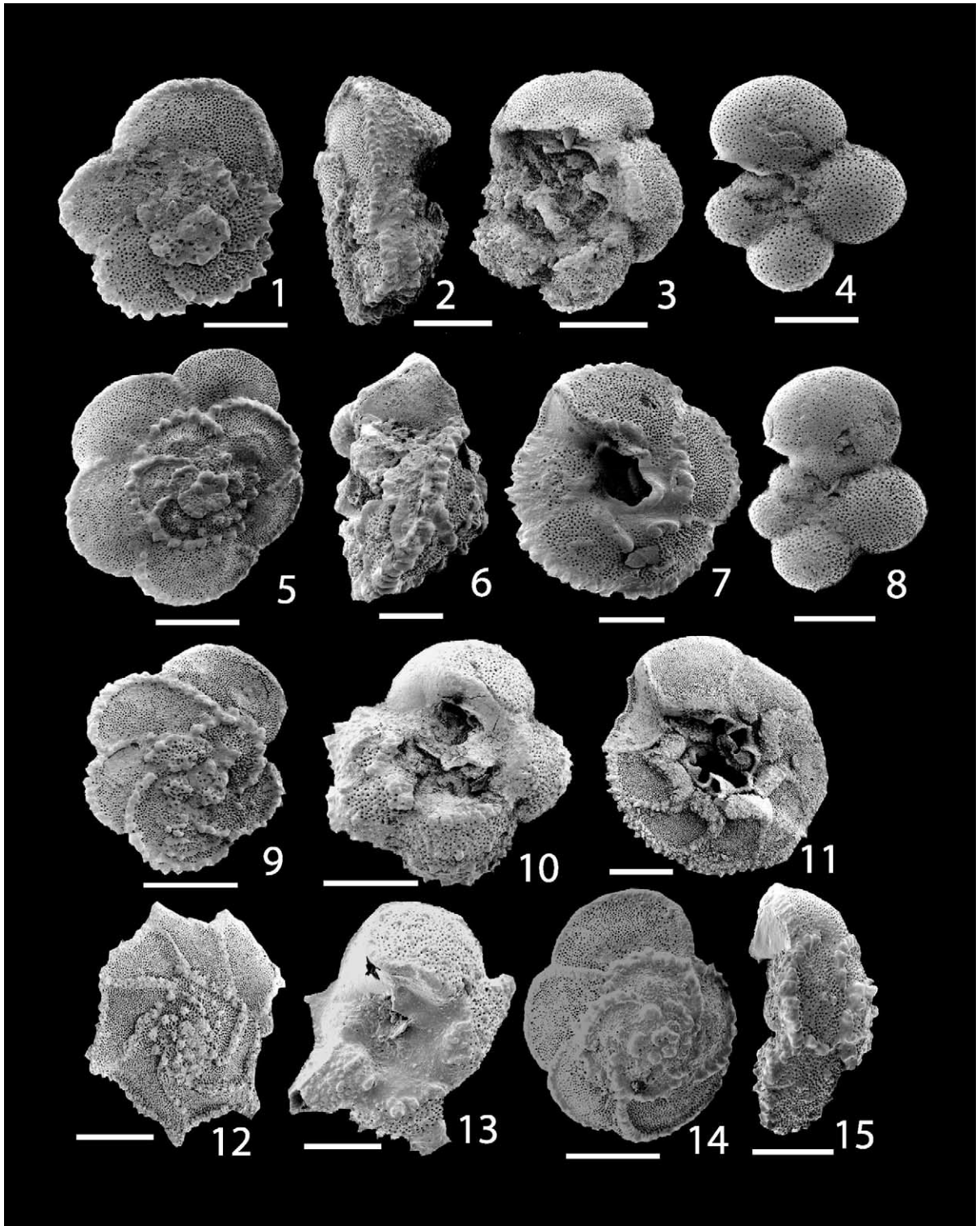


Plate I.



(>150- $\mu\text{m}$  size fraction), including increased abundances of *Rugoglobigerina rugosa*, *Rugoglobigerina macrocephala*, *Heterohelix dentata*, *H. planata*, decreased abundances of *Laeterohelix labelosa* and *Planoglobulina carseyae* (Plates II and III), and unusually large (>150  $\mu\text{m}$ ) *Guembelitria cretacea* (Fig. 3). The CF1/CF3 hiatus or condensed interval also marks a lithological change from macrofossil-rich shale to marly shale devoid of macrofossils (Fig. 2), and coincides with the culmination of the Maastrichtian global cooling trend around 65.5 Ma (Barrera, 1994; Li and Keller, 1998a,c; Olsson et al., 2001).

### 5.3. Zone CF1

Zone CF1 marks the range of *Plummerita hantkeninoides* which spans the last 300 000 kyr of the Maastrichtian (Pardo et al., 1996; Li and Keller, 1998a,b). At Qreiya *P. hantkeninoides* first appears at 1.8 m below the K/T boundary along with *Rugoglobigerina reicheli* and coincident with the last appearances of *Gansserina gansseri* and *Kassabiana falsocalcarata* (Plate I). The juxtaposition of these species suggests a short hiatus or condensed interval that spans zone CF2 and probably the upper part of CF3, as noted above.

In the uppermost part of zone CF1, two undulating erosional surfaces with truncated burrows mark short hiatuses below the thin red layer that marks the K/T boundary, and about 10 cm below the red clay layer (Fig. 2). This interval may correspond to the global cooling and lower sea-level during the last 100 000 years of the Maastrichtian (Li and Keller (1998c), or the last 22 000 years (Olsson et al. (2001).

Based on faunal changes and comparison with zone CF1 assemblages elsewhere in the Tethys region, only about 1/3 of zone CF1 may be present at Qreiya. For example, zone CF1 spans nearly 6 m in the nearby Wadi Hammama section (Tantawy, in press), 2–8 m in various sections in the Negev (Abramovich et al., 1998), 6 m at El Kef, Tunisia (Li and Keller, 1998b), 9 m at Elles, Tunisia, Abramovich and Keller (2002), and 3.5 m at Agost, Spain (Pardo et al., 1996). However, at least part of the variability in the sediment thickness of zone CF1 in the Negev and south-eastern Egypt (Gebel Qreiya and Wadi Hammama) is likely linked to tectonic activity and irregular paleotopography (Hendriks et al., 1987; Hendriks and Luger, 1987; Abramovich et al., 1998).

## 6. Cretaceous/Tertiary boundary

### 6.1. Zone P0

Zone P0 marks the K/T boundary and is defined as the interval between the extinction of Cretaceous tropical planktic foraminifera and the first appearance of *Parvularugoglobigerina eugubina* and/or *P. longiapertura* (Fig. 2; Keller et al., 1995). Lithologically, zone P0 is marked by a dark clay layer with a thin red clay at the base. At Qreiya the K/T boundary interval and zone P0 are at least partially preserved as indicated by the presence of a 1-cm-thick red clay layer that overlies an undulating erosional surface. An Ir anomaly of 5.4 ppb was identified in this red clay layer (sample 11.5; Keller et al., in press)

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Plate I. Globotruncanids, scale bar = 200  $\mu\text{m}$ . All specimens from the latest Maastrichtian zone CF1 (*Plummerita hantkeninoides*) at Qreiya, Egypt.

- 1–3. *Globotruncana aegyptiaca*.
- 4, 8. *Globotruncanella subcarinatus*.
- 5–7. *G. dupeublei*.
- 9, 10. *G. rosetta*.
- 11. *Globotruncanita stuarti*.
- 12, 13. *Kassabiana pseudocalcarata*.
- 14, 15. *Globotruncanita conica*.

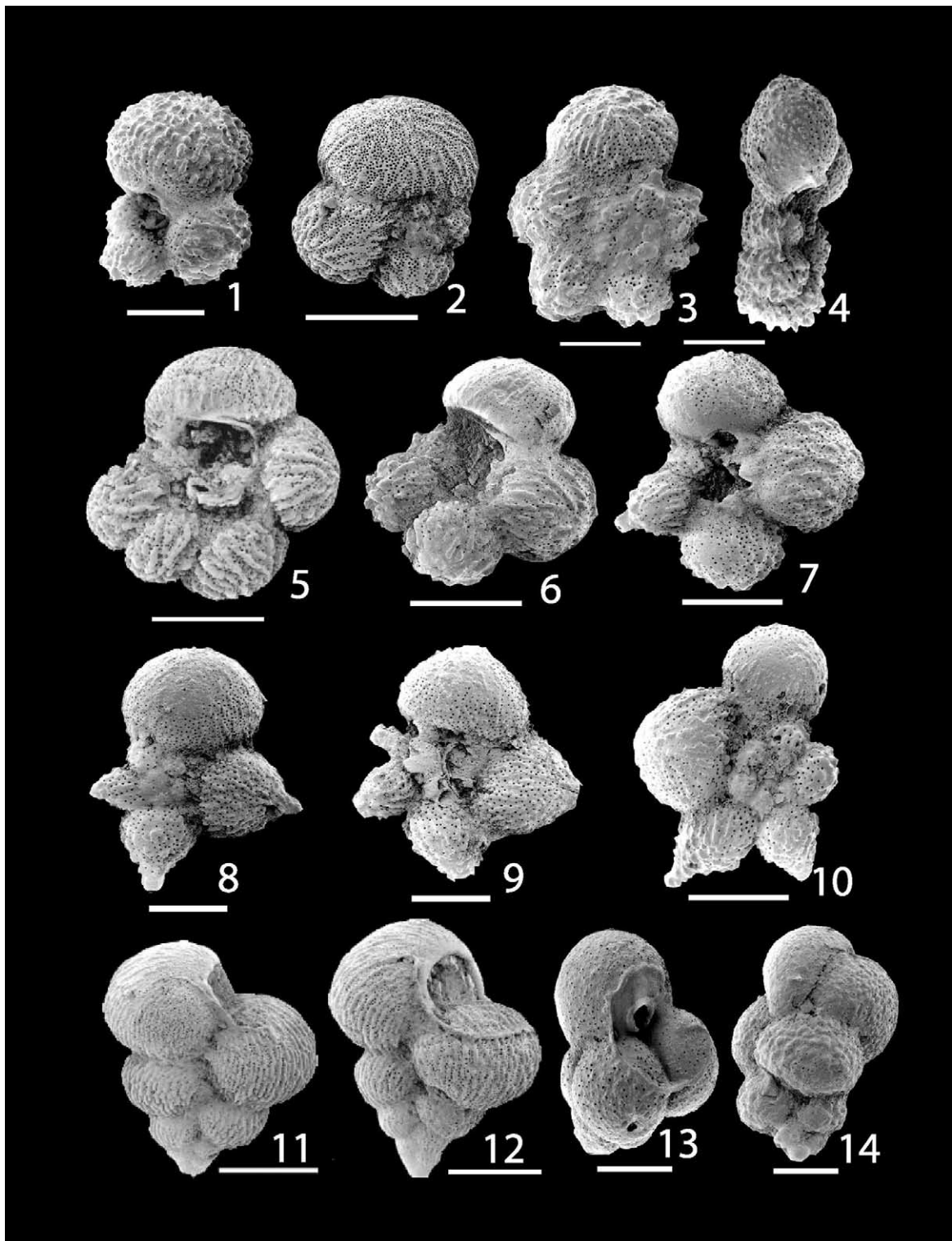


Plate II.

and marks the first reported occurrence of this anomaly in Egypt. Throughout Egypt, including the Sinai and Negev, the K/T boundary interval is generally condensed, often highly bioturbated, marked by erosion surfaces and absence of the characteristic K/T boundary clay and basal red layer (Keller and Benjamini, 1991; Shahin, 1992; Samir, 1994; Faris, 1997; Luger et al., 1989; Tantawy et al., 2001).

## 7. Early Paleocene

### 7.1. Zone Pla

This zone is defined by the range of *Parvularugoglobigerina eugubina* and/or *P. longiapertura* (Fig. 2; Plate V). At Qreiya, the first Tertiary species present at the base of the 50-cm-thick fissile dark gray shale that overlies the red clay of zone P0 (sample 11; Fig. 4) includes, *Globoconusa daubjergensis*, *Parvularugoglobigerina eugubina*, *P. longiapertura*, *P. extensa* (= *G. conusa*), *Eoglobigerina edita* and *E. eobulloides*, followed by *Subbotina triloculinoides*, *S. trivialis* and *Woodringina claytonensis* (Plates IV–VI). Few Maastrichtian species are present and most of these are probably reworked (Fig. 4). The top of zone Pla is identified by the disappearances of *P. eugubina* and *P. longiapertura* at 50 cm (sample 6) above the red clay layer.

There are several indicators that mark this short Pla zone as incomplete or condensed. Evidence for a basal Danian hiatus includes: (1) the simultaneous first appearances of six Danian spe-

cies, including *Parvularugoglobigerina eugubina* and *P. longiapertura*, the index species for zone Pla above the red clay layer (Fig. 4); (2) the relatively low abundance of *Guembelitra* (< 30%), as compared with its characteristic dominance (> 80%) in basal Danian sediments worldwide (see Keller et al., 1995; Luciani, 1997, 2002; Apellaniz et al., 1997); (3) *Subbotina triloculinoides* and *S. trivialis*, which are known to evolve in the upper part of zone Pla already appear 20–30 cm above the red clay; (4) the presence of abundant reworked Maastrichtian species in zone Pla; (5) the very short interval (50 cm) represented by zone Pla suggests a condensed early Danian, as also observed in the Negev (Keller and Benjamini, 1991); and (6) the presence of common Danian species in the larger than 63µm size fraction; Danian species in the lower part of zone Pla are generally smaller (Keller et al., 2001a). A hiatus or condensed sedimentation in the early Danian zone Pla has been observed in numerous sections and may be related to early Danian cooling and sea-level changes (MacLeod and Keller, 1991; Keller and Stinnesbeck, 1996).

### 7.2. Zone Plb

This zone is defined as the interval between the last occurrence of *Parvularugoglobigerina eugubina* and/or *P. longiapertura* and the first appearance of *Parasubbotina varianta*. Zone Plb is condensed partly due to dissolution at the Plb/Plc boundary and a hiatus at the Pla/Plb boundary. Evidence for a Pla/Plb hiatus is indicated by: (1) the abrupt disappearance of *P. longiapertura* immedi-

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Plate II. Rugoglobigerinids, scale bar = 200 µm. All specimens from the latest Maastrichtian zone CF1 (*Plummerita hantkeninoides*) at Qreiya, Egypt.

- 1, 2. *Rugoglobigerina macrocephala*.
- 3, 4. *R. scotti*.
- 5, 6. *R. rugosa*.
7. *Plummerita hantkeninoides* with one spine only.
- 8–10. *P. hantkeninoides*.
- 11, 12. *Pseudotextularia elegans*.
13. *Guembelitra trifolia*.
14. *G. irregularis*.

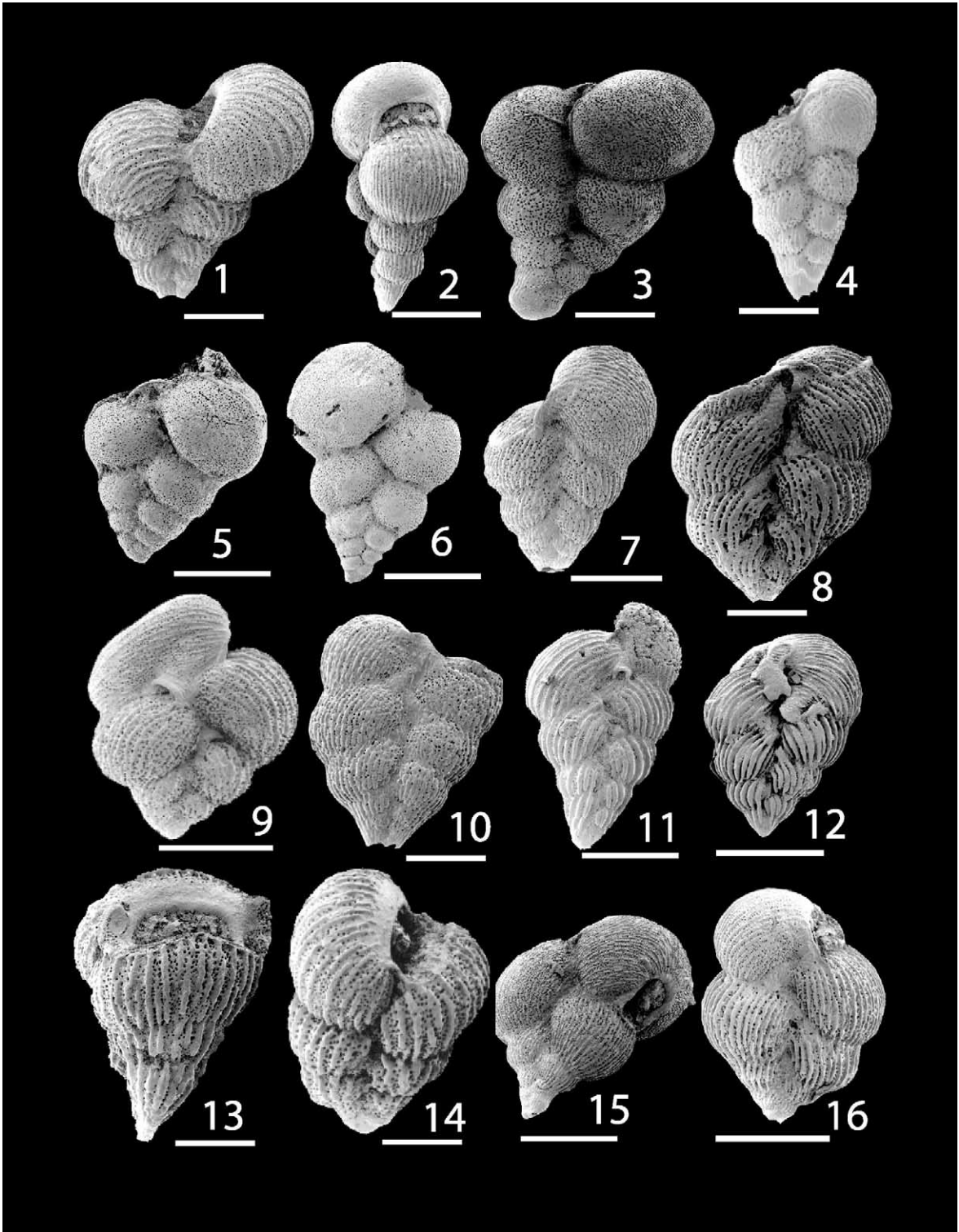


Plate III.

ately after its most abundant stage (53%); (2) the peak abundance of *P. extensa* (formerly *G. conusa*) to 63% immediately above the disappearance of *P. longiapertura*; (3) the simultaneous first appearances of *P. alabamensis*, *Woodringina hornerstownensis*, and *Globanomalina taurica*. The condensed upper part of P1b, due to dissolution and/or a hiatus, is also marked by strong abundance changes in *P. extensa*, *Subbotina triloculinoides*, and *Woodringina claytonensis* (Fig. 4; Plates IV–VI).

### 7.3. Zone Plc

Danian assemblages in the 5-m overlying zone P1b indicate a zone Plc age which is defined as the interval from the first appearance of *Parasubbotina varianta* to the first appearance of *Praemurica trinidadensis* (Figs. 2 and 4; Plate VI). The latter index species was not observed in the studied interval. Zone Plc can be subdivided into Plc(1) and Plc(2) based on the first appearance of *Praemurica inconstans* which first appears at about 3.8 m above the boundary clay and just below a 1-m-thick dissolution interval that contains only rare foraminifera. Relatively impoverished Danian Plc(2) assemblages are present above this dissolution interval (Fig. 4). There are strong and abrupt faunal assemblage and relative abundance changes within Plc(1) that indicate another hiatus at 2.5 m above the boundary clay. Evidence for this hiatus includes: (1) a sharp lithological break from marly shale to shale; (2) the abrupt reap-

pearance of abundant *Guembelitra cretacea* and *G. daubjergensis*; (3) the abrupt decrease of abundant *Woodringina claytonensis*, *W. hornerstownensis*, *Globanomalina pentagona* and *P. varianta* (Fig. 4; Plates IV and VI).

## 8. Foraminiferal populations

Late Maastrichtian Tethyan assemblages of middle to outer neritic (100–250 m) and upper bathyal (250–500 m) depths typically have 56–65 species (Keller, 1988, 1996; Keller et al., 1995; Luciani, 1997; Apellaniz et al., 1997; Olsson, 1997; Orue-etxebarria, 1997; Masters, 1997; Abramovich et al., 1998; Abramovich and Keller, 2002). The Qreiya assemblages, deposited in middle to outer neritic depths, differ in that species richness is only about half, averaging 25 species in zone CF3 and 30–35 species in CF1 (Fig. 3). Such low species richness is generally only observed in very shallow (< 100 m) or restricted Tethyan environments where deeper dwelling species are excluded (e.g. Texas, Alabama, southern Tunisia; Keller, 1989; Olsson and Liu, 1993; Keller et al., 1998, 2002).

At Qreiya, the unusually impoverished late Maastrichtian planktic foraminiferal assemblages appear to mimic the post-K/T paleoenvironment (usually interpreted as high stress) in terms of low species diversity and assemblages dominated by ecological generalists and opportunists, particularly in the small size fraction (63–150 µm). Clues

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Plate III. Maastrichtian biserial taxa, scale bar = 200 µm. All specimens from the latest Maastrichtian zone CF1 (*Plummerita hantkeninoides*) at Qreiya, Egypt.

1. *Heterohelix striata*.
2. *H. globulosa*.
3. *H. navarroensis*.
4. *H. dentata*.
- 5, 6. *H. planata*.
- 7, 8. *Laeterohelix (Heterohelix) labellosa*.
9. *Pseudoguembelina palpebra*.
10. *P. hariaensis*.
- 11, 12. *P. costulata*.
- 13, 14. *Pseudotextularia elegans* (formerly *P. deformis*).
- 15, 16. *Planoglobulina carseyae*.

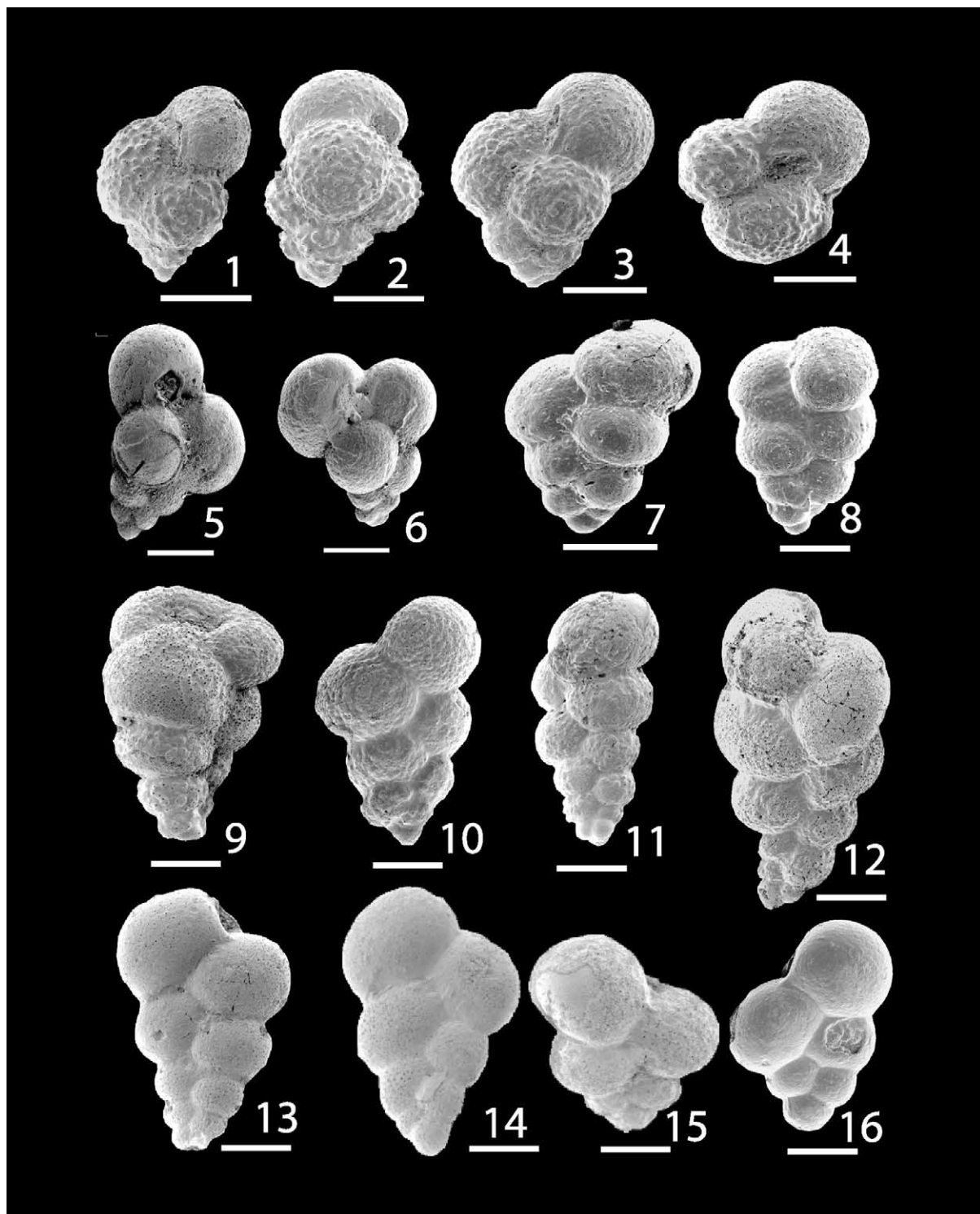


Plate IV.



to the nature of this late Maastrichtian low diversity environment can be gained from the presence/absence of ecological specialists that typically inhabit the Tethys, and the relative abundance variations of the dominant species (ecological generalists and opportunists) and their environmental preferences as observed from paleobiogeographic distribution patterns.

## 9. Ecological specialists

The species group interpreted as ecological specialists consists of tropical and subtropical species with narrow tolerance limits and restricted geographic range, although they may migrate in small numbers into higher latitudes during climatic warming (Kucera and Malmgren, 1998). Species of this group are generally of large size (> 150 µm), complex morphology and highly ornamented, heavily calcified tests with keels, ridges, and spines, and frequently many chambers and large apertures. They include most globotruncanids, racemiguembelinids, planoglobulinids and rugoglobigerinids (Plates I and II).

At Qreiya, tropical–subtropical ecological specialists are rare or absent, except for rugoglobigerinids (Fig. 3). Globotruncanids, the largest group of ecological specialists is surprisingly rare. Although a total of ten globotruncanid species are recorded, only 4–8 species are present in any given sample, and only *Globotruncana esnehensis* is consistently present (< 1–3%; Table 1). Many common late Maastrichtian globotruncanids are absent, including *G. arca*, *G. orientalis*, *G. rosetta* and *R. contusa*. The combined relative abundance of globotruncanids is very low, with peaks of 5% and 6% in zone CF3, but only one sample with a

maximum of 2% in zone CF1 (Table 1; Fig. 5). This is an exceptionally low globotruncanid species richness and abundance for a middle to outer neritic environment of the eastern Tethys. In comparison, 16 globotruncanid species are reported from the Hor Hahar section of the Negev, Israel, with a combined average abundance of 15% in CF3 and 5% in zone CF1 (Abramovich, 1997, Abramovich et al., 1998). At Elles, Tunisia, 18 globotruncanids are reported with a combined abundance of 25–30% in zone CF3 and 5% in CF1 (Abramovich and Keller, 2002). In addition to globotruncanids, many other ecological specialists are also extremely rare or absent at Qreiya, including all gublerinids, racemiguembelinids and planoglobulinids (*brazoensis*, *P. multicamerata*, *P. averculinoides*).

Among rugoglobigerinids, only *Plummerita hantkeninoides*, *Tritinella scotti* and possibly *Rugoglobigerina reicheli* are largely restricted to the low latitude Tethys. These surface dwellers rarely appear in middle latitudes and are generally absent beyond 30° north or south (Li and Keller, 1998a; Olsson et al., 2001; MacLeod et al., 2001). *Plummerita hantkeninoides* evolved near the lower part of the latest Maastrichtian warm event (~65.3 Ma) and disappeared at the K/T boundary (Masters, 1993; Pardo et al., 1996; Li and Keller, 1998c). At Qreiya, *P. hantkeninoides* is significantly more abundant (3–14%) than in the Negev (1–4% at Hor Hahar; Abramovich, 1997), Tunisia (1–2% at Elles; Abramovich and Keller, 2002), or Spain (1% at Agost; Pardo et al., 1996). The relatively high abundances of *P. hantkeninoides* (3–14%) and *R. reicheli* (1–8% in CF1) contribute to the high abundance of the rugoglobigerinid surface dwellers (40%; Fig. 5) during the warm climate of zone CF1 at Qreiya. *Tritinella*

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Plate IV. Danian biserial and triserial taxa, scale bar = 50 µm. All specimens from the early Danian zone Pla (*P. eugubina*) at Qreiya, Egypt, except 5 and 6.

- 1–4. *Guembelitria cretacea*.
- 5, 6. *G. cretacea* from the Maastrichtian zone CF1.
- 7–12. *Woodringina hornerstownensis*.
- 13, 14. *Chilloguembelina midwayensis*.
- 15, 16. *Woodringina claytonensis*.

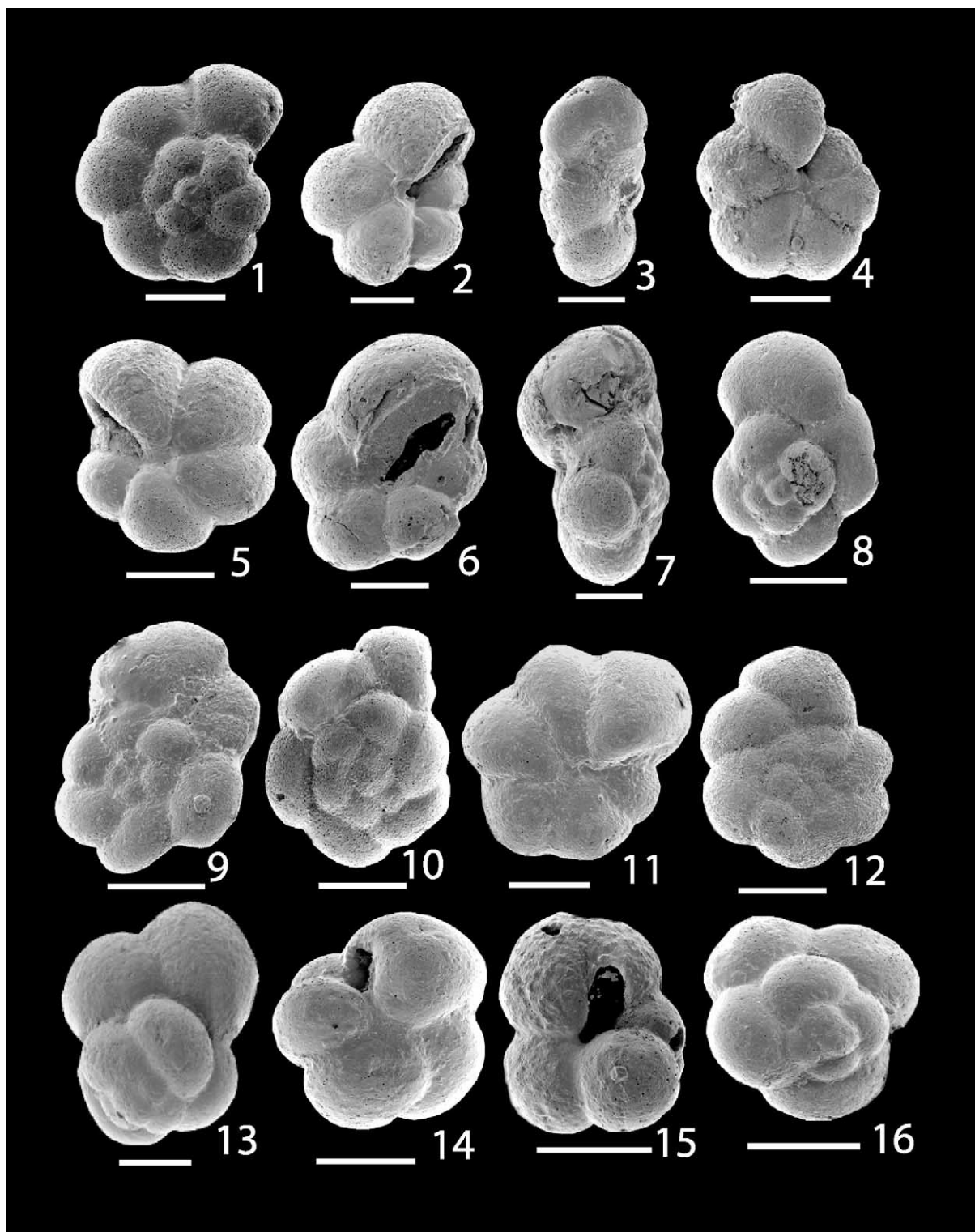


Plate V.



*scotti* is rare in zone CF1 (1–2%), but relatively common in zone CF3 (4–6%), except for a peak of 24% in sample 35 which may be due to dissolution and breakage of more fragile species (Fig. 3; Table 1).

On a global basis, ecological specialists suffered severely during the late Maastrichtian cooling and all went extinct at or near the K/T boundary (Keller, 1988, 1996; Masters, 1997; Orue-etxebarria, 1997; Olsson, 1997; Luciani, 1997; Abramovich et al., 1998). No species of this group dominated planktic foraminiferal assemblages at any time during the late Maastrichtian (Keller, 1988; 1996; Malmgren, 1991; Luciani, 1997; Nederbragt, 1998; Li and Keller, 1998a,b). However, in central Egypt unique environmental conditions severely limited species diversity. This is indicated by the very low species richness of the Qreiya assemblages, which is primarily due to the absence or rarity of the largely subsurface dwelling ecological specialists, including globotruncanids, gublerinids and planoglobulinids. In contrast, rugoglobigerinid surface dwellers thrived (~40%), at least during the warm event of zone CF1 (Fig. 5). This suggests peculiarities in the watermass stratification (e.g. expanded oxygen minimum zone, low productivity, absence of thermal stratification) possibly as a result of restricted circulation in central Egypt.

## 10. Ecological migrants

Ecological migrants are loosely defined here as a group of species that thrived in warm tropical and subtropical waters and migrated into middle and higher latitudes during times of climate warming. They are thus differentiated from

ecological specialists by common or consistent presence in middle latitudes and hence greater environmental tolerance outside the Tethys. This group includes mostly surface dwellers (rugoglobigerinids, pseudotextularids, pseudoguembelinids; Plates II and III) and, except for rugoglobigerinids, none show major abundance variations and they are therefore not discussed further.

## 11. Ecological generalists

Heterohelicids are here interpreted as ecological generalists. They are the garden weeds of the foraminiferal community. These biserial taxa are characterized by medium or small test sizes, simple morphologies, little surface ornamentation (Plates III and IV), and nearly global biogeographic range. They appear to have tolerated significant fluctuations in temperature and/or salinity, oxygen and nutrients and can therefore be considered ecological generalists. In particular, the isotopic compositions of smaller species (*Heterohelix globulosa*, *H. dentata*, *Laeterohelix labellosa*, *H. planata* and *H. navarroensis*, Plate III) suggest that they lived in deeper less oxygenated waters, and may have thrived at times of expanded oxygen minimum zones (Boersma and Premoli Silva, 1989; Barrera and Keller, 1994; MacLeod et al., 2001), whereas their global biogeographic distribution suggests a tolerance for temperature changes (Nederbragt, 1998). *Heterohelix globulosa*, the most abundant of these species, tends to exhibit a preference for continental margins (Leckie, 1987; Keller, 1989, 1996; Malmgren, 1991).

At Qreiya, heterohelicids dominate (50–70%; Fig. 5) in the > 150- $\mu$ m size fraction, with *Hete-*

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Plate V. Parvularugoglobigerinids, scale bar = 50  $\mu$ m. All specimens from the early Danian zone Pla (*P. eugubina*) at Qreiya, Egypt.

- 1–8. *Parvularugoglobigerina eugubina*.
- 9–12. *P. longiapertura*, note shape of chambers, diagonal sutures and compressed chambers.
- 13–16. *P. extensa* (formerly *Globoconusa conusa*).

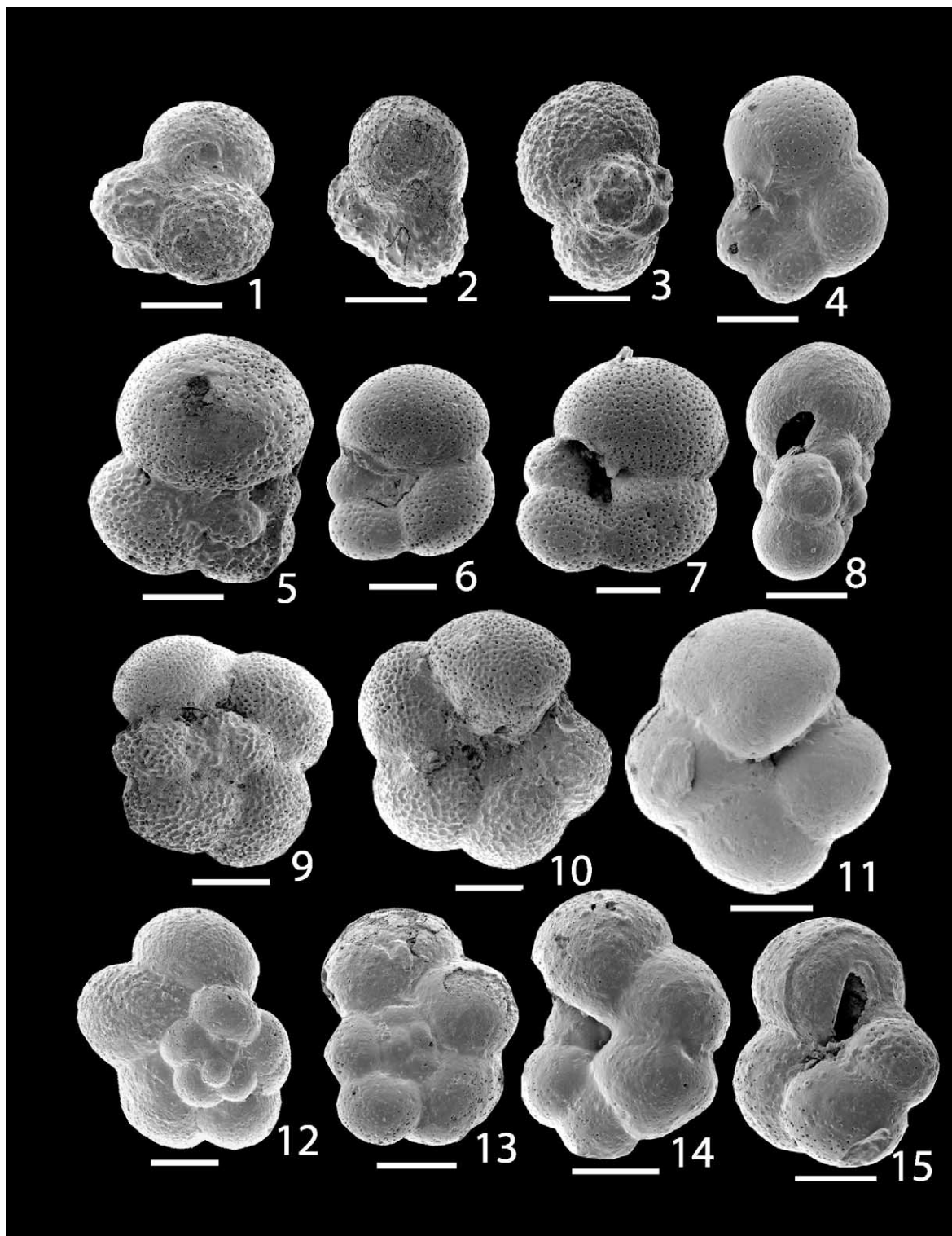


Plate VI.

*rohelix globulosa* most abundant (Fig. 3). *Laeterehelix labellosa* is more common in CF3, and *H. punctulata*, *H. planata* and *H. dentata* in CF1 (Fig. 3). In the smaller size fraction (63–150 µm) heterohelicids are less abundant, except for a short interval in zone CF3 where *H. navarroensis* dominates, and *H. globulosa* and *H. dentata* increase in zone CF1 (Fig. 5). Late Maastrichtian heterohelicid dominance has also been observed in Tunisia, Israel, Italy, Spain, Texas, Denmark and DSDP Site 525 (Keller, 1988, 1989; Nederbragt, 1991, 1998; Malmgren, 1991; Keller et al., 1995, 1993; Luciani, 1997; Abramovich et al., 1998; Li and Keller, 1998a; Abramovich and Keller, 2002).

Dominance of ecological generalists at Qreiya in central Egypt suggests decreased water mass stratification and may reflect an expanded oxygen minimum zone. Higher relative abundances of *Heterohelix navarroensis* in CF3 and of *H. dentata* and *H. planata* in CF1 suggest changing water mass characteristics, though specific habitats and ecological requirements of particular heterohelicid species are still largely unknown.

## 12. Ecological opportunists

The most unusual aspect of the late Maastrichtian faunal assemblages at Qreiya is the dominance of *Guembelitra cretacea* (> 63-µm size fraction; Fig. 4; Plate 4). This species has been observed to dominate after the K/T boundary impact event in the early Danian zones P0 and lower Pla, and has therefore been labeled ecological opportunist or

disaster species. *Guembelitra cretacea* is generally present in very low frequencies (<1%) in late Maastrichtian faunal assemblages of normal open marine environments, but more abundant (10–20%) in shallow nearshore environments, such as those of Brazos, Texas (Keller, 1989), Denmark (Schmitz et al., 1992; Keller et al., 1993), or southern Tunisia (Keller et al., 1998). However, at times of low species diversity and reduced species abundances *Guembelitra* species tend to produce opportunistic blooms, as is well known for the K/T boundary clay and early Danian. In the Negev, Abramovich et al. (1998) noticed three *Guembelitra cretacea* blooms in the late Maastrichtian. But no such high abundances of *G. cretacea* as at Qreiya (60–90%) have been observed before. However, recently a larger, elongate and high-spined new species, *Guembelitra dammula*, was observed with the same high abundances in zone CF1 from sections along the coast of the Black Sea (Bjala, Bulgaria; Adatte et al., 2002b).

High abundances of the ecological opportunist *Guembelitra* characterize crisis conditions at the K/T boundary as well as the anoxic event near the Cenomanian/Turonian transition (e.g. Leckie, 1987; Apellaniz et al., 1997; Luciani, 1997; Keller et al., 2001b, 2002). The persistent relatively high abundances of this species group in shallow nearshore areas during the late Maastrichtian suggest a high tolerance for salinity, nutrient and temperature fluctuations. In the Gafsa Basin (Seldja) of southern Tunisia, *Guembelitra* dominance is associated with a warm humid climate, high rainfall, low salinity, high organic matter influx from near-

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Plate VI. Danian, scale bar = 50 µm. All specimens from the early Danian at Qreiya, Egypt.

1. *Parvularugoglobigerina extensa* (formerly *G. conusa*).
- 2–3. *Globoconusa daubjergensis*.
- 5–7. *Subbotina triloculinoides*.
- 4, 8. *Parasubbotina varianta*.
- 9–11. *Globigerina (Eoglobigerina) pentagona*.
12. *Hedbergella monmouthensis* (poorly preserved).
- 13, 14. *H. monmouthensis*, note poor preservation suggests that these specimens are reworked.
15. *Eoglobigerina eobulloides*.

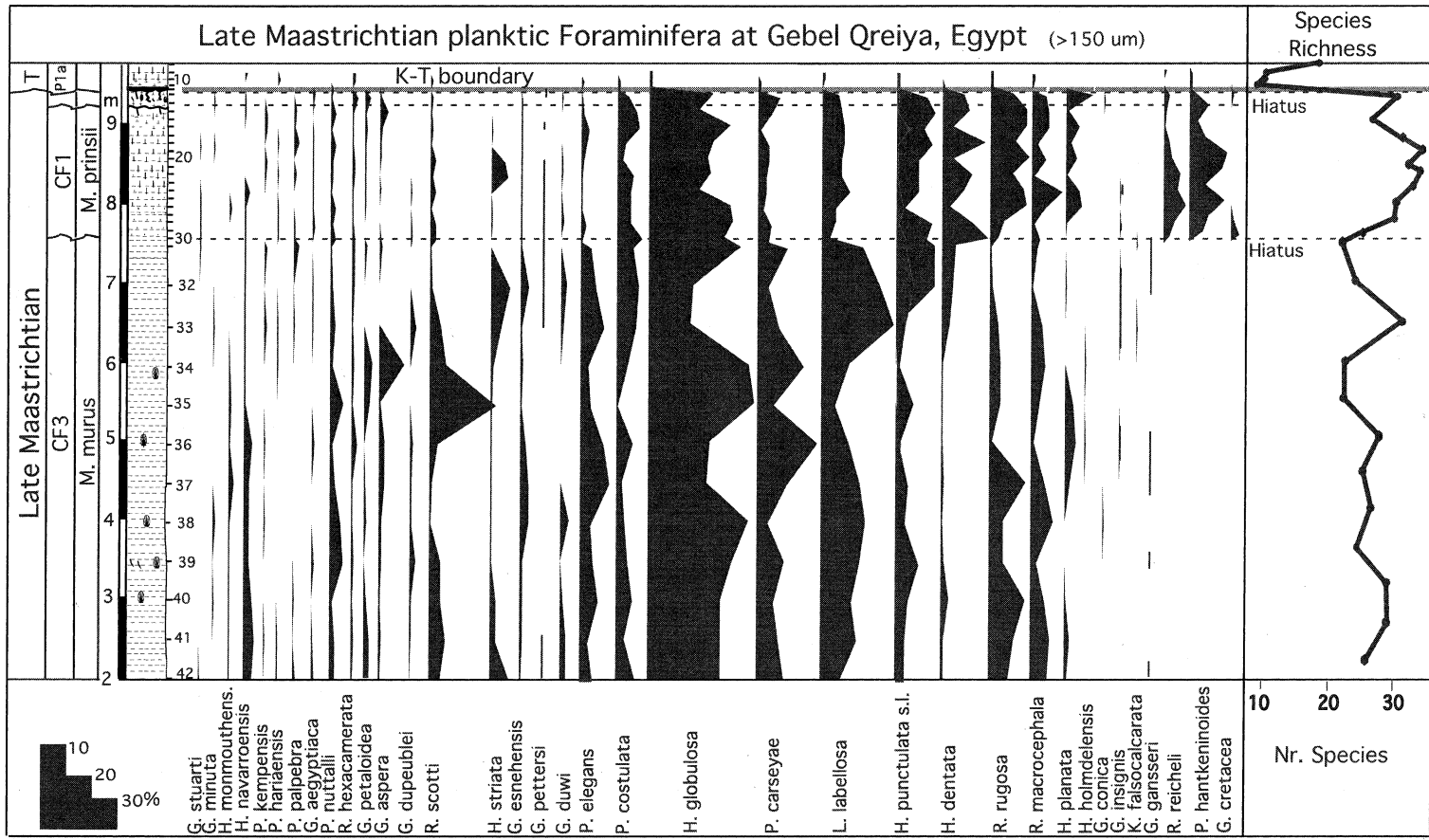


Fig. 3. Planktic foraminiferal species abundances in the >150- $\mu$ m size fraction of the late Maastrichtian at Gebel Qreiya, Egypt. Note that the late Maastrichtian is dominated by low oxygen tolerant small heterohelicid species (*H. globulosa*, *H. labellosa*, *H. dentata*, *H. planata*, *H. punctulata*). Rugoglobigerinids increased in relative abundances during the last 300000 kyr of the Maastrichtian (*R. rugosa*, *R. macrocephala*, *R. reicheli*, *Plummerita hantkeninoides*). Dashed lines mark hiatuses. Zone CF2 appears to be missing (65.45–65.3 Ma), zone CF1 is only partially present, the earliest Danian zone P0 is restricted to the red layer, and the lower part of zone P1a is missing. Calcareous nannofossil zones from [Tantawy, in press](#).

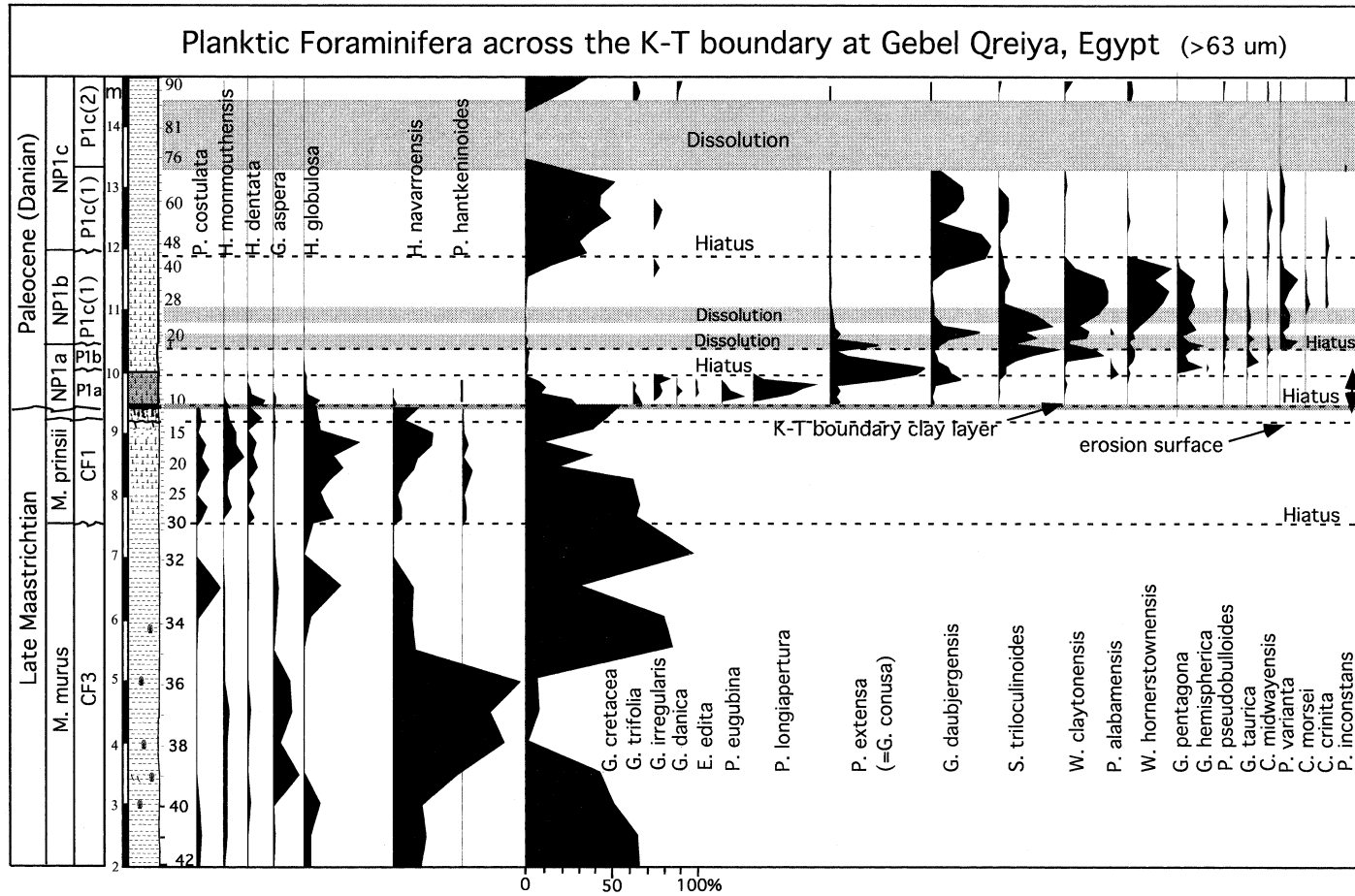


Fig. 4. Planktic foraminiferal species abundances in the smaller (63–150 μm) size fraction of the late Maastrichtian to early Paleocene at Gebel Qreiya, Egypt. Note the unusually high abundance of *Guembeltria cretacea* in the late Maastrichtian, and the alternation of abundant *Guembeltria* with abundant small heterohelelicids (e.g. *H. navarroensis*, *H. globulosa*, *H. dentata*). This pattern is unknown from late Maastrichtian sequences, and similarly high abundances of *Guembeltria* are only recorded from the post-K/T boundary intervals of zones P0 and P1a. The absence of high *Guembeltria* immediately after the K/T boundary is due to a hiatus that removed P0 and the lower part of P1a. Calcareous nannofossil zones from [Tantawy, in press](#).

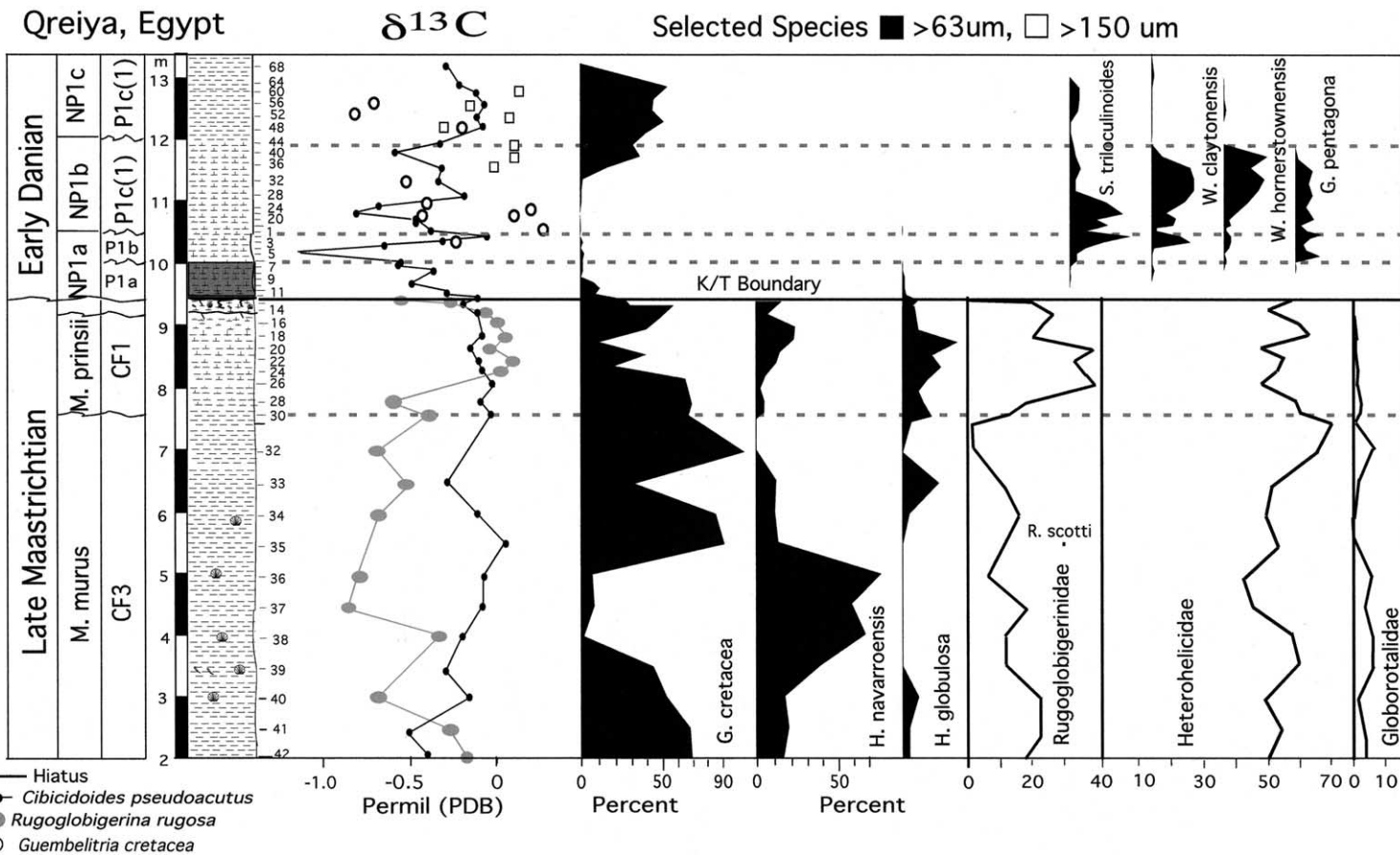


Fig. 5. Carbon isotope values of the benthic species *Cibicidoides pseudoacutus* and planktic species *Rugoglobigerina rugosa* for the late Maastrichtian and *Guembeltria cretacea*, *Woodringina hornerstownensis*, *Globigrina pentagona*, *Subbotina triloculinoides* for the early Danian at Gebel Qreiya, Egypt. Note the inverse surface-to-deep  $\delta^{13}\text{C}$  gradient in zone CF3, similar to that characteristically observed at the K/T boundary in low to middle latitudes. Relative abundance fluctuations of selected species suggest that late Maastrichtian *Guembeltria* and *Heterohelix* species thrived in low diversity assemblages associated with low productivity, but eutrophic waters, similar to early Danian low diversity assemblages.



by terrestrial areas and hence eutrophic waters, and low oxygen bottom water conditions (Keller et al., 1998). In the same area, the ecological generalist *Heterohelix navarroensis* thrived at times of low *Guembelitra* abundances. The same pattern is observed at Qreiya (Fig. 5), which suggests that similar environmental conditions prevailed in the deeper water central Egypt basin during the late Maastrichtian. At Qreiya, carbon isotopes provide further clues to the environmental conditions in which *Guembelitra* thrived.

### 13. Carbon isotopes

Foraminifera are well preserved at Qreiya. However, even well preserved tests tend to be partially recrystallized with up to 50% diagenetic calcite (Pearson et al. (2001). Recrystallization of foraminiferal tests occurs upon settling in the cool waters of the ocean floor. As a result, oxygen isotopic trends shift towards more positive (cooler) values and carbon isotopes towards more negative values (lower productivity). Isotopic values are thus biased towards cooler temperatures and lower productivity. However, carbon isotope differentials between species tend to be retained during diagenesis, but with the effect of reducing the differential depending on the degree of diagenesis. Thus, in completely recrystallized tests,  $\delta^{13}\text{C}$  values of benthic and planktic species converge (Pearson et al., 2001). At Qreiya the carbon isotope differential between benthic and planktic species shows distinct trends that indicate changes in productivity, as is also suggested by correlative changes in species populations and faunal assemblages.

The late Maastrichtian surface-to-deep  $\delta^{13}\text{C}$  gradient of the benthic foraminifer *Cibicidoides pseudoacutus* and planktic foraminifer *Rugoglobigerina rugosa* at Qreiya is very unusual. Benthic  $\delta^{13}\text{C}$  values show relatively minor variations between 0‰ and –0.3‰, though there are major excursions in planktic  $\delta^{13}\text{C}$  values (Fig. 5). Near the base of the section, a small positive surface-to-deep  $\delta^{13}\text{C}$  gradient is present. This is followed by a negative planktic  $\delta^{13}\text{C}$  excursion of 0.5–0.8‰ and establishes an inverse surface-to-deep gra-

dient for the remainder of zone CF3 and into the base of CF1 (Fig. 5; Table 3). A positive shift of 0.8‰ in planktic  $\delta^{13}\text{C}$  values reestablishes a slightly positive surface-to-deep gradient in zone CF1. Near the top of the Maastrichtian (top 20 cm), planktic  $\delta^{13}\text{C}$  values drop by 0.6‰ and are again more negative than benthic values, as is characteristic of the K/T boundary in general.

Is the observed reversal in the surface-to-deep gradient real or an artifact of diagenesis? Recrystallization of foraminiferal tests occurs in the cooler waters of the ocean floor, which shifts planktics towards more negative carbon values than benthic species, and hence reduces the surface-to-deep gradient. Total (100%) recrystallization would result in convergence of planktic and benthic values (Pearson et al., 2001). Thus, recrystallization alone cannot account for the more negative planktic values during the late Maastrichtian at Qreiya, and strongly suggests that surface productivity was very low. The unusual low diversity *Guembelitra*-dominated planktic foraminiferal assemblages support this interpretation.

Benthic  $\delta^{13}\text{C}$  values show only a minor decrease (–0.3‰) across the K/T boundary, consistent with benthic patterns elsewhere (Keller and Lindinger, 1989; Zachos et al., 1989). However, in the early Danian Pla–Plb interval benthic values continued to drop and reached minimum values at the Pla/Plb hiatus (Fig. 5). The first recovery is indicated at the Plb/Plc boundary and hiatus by a brief positive excursion, followed by another negative excursion in the lower part of Plc(l). Similar positive and negative excursions were observed at these time intervals in the Negev (Magaritz et al., 1992) and South Atlantic (Barrera and Keller, 1994).

It is difficult to evaluate the surface-to-deep  $\delta^{13}\text{C}$  gradient of the early Danian because planktic foraminiferal species are extremely small, short ranging, and often present in insufficient quantities for analysis. In addition, diagenetic effects due to partial recrystallization and possibly test infillings may have obliterated original signals in these small species. At Gebel Qreiya, a number of planktic species were analyzed with mixed results that suggest diagenetic overprints and possibly species effects. *Guembelitra cretacea*, *Wood-*

*rigina hornerstownensis*, and *Globigerina pentagona* have generally lighter, or similar values as the benthic species *Cibicidoides pseudoacutus*. Only *Subbotina tiloculinoidea* from samples in the upper part of zone Plc has  $\delta^{13}\text{C}$  values that are generally heavier (five out of seven samples) than the benthic species (Fig. 5). These data reflect the difficulties of determining surface-to-deep gradient changes in the early Danian and demonstrate the need for further analysis of well-preserved Danian assemblages.

#### 14. Discussion

The Cretaceous–Tertiary boundary impact horizon is characterized by the mass extinction of tropical and subtropical planktic foraminiferal species, followed by opportunistic blooms of *Guembelitra cretacea* (e.g. Luciani, 1997; Masters, 1997; Olsson, 1997; Orue-extebarria, 1997; Keller, 1996, 2001). At least some of the early Danian species are interpreted to have repopulated the world oceans from the high latitudes, which served as refuge for ecological generalists (MacLeod and Keller, 1994). This pattern has been considered unique to the K/T boundary as a result of the biological devastation of the impact event.

New data from late Maastrichtian planktic foraminiferal assemblages at Qreiya in central Egypt challenge these interpretations. The Qreiya section shows that both the opportunist *Guembelitra cretacea* and the small ecological generalists (*Heterohelix*) lived, and at times thrived in the tropics, as also observed in southern Tunisia and Brazos River, Texas (Keller, 1989; Keller et al., 1998, 2002). Ecological opportunists and generalists thus appear to have been an integral part of planktic foraminiferal assemblages in the tropics, and indeed across latitudes, during the late Cretaceous. But they remained a minor, though sometimes invisible, part of the planktic foraminiferal assemblages in normally productive and well-stratified oceans, because of their low abundances (<1%) and very small size (36–100  $\mu\text{m}$ ) within assemblages of generally large ecological specialist species (>150  $\mu\text{m}$ ). At times of ecological stress,

here interpreted as low productivity, oligotrophic or eutrophic environments, ecological specialists disappeared, and ecological generalists and opportunists thrived.

The environmental conditions in which *Guembelitra* thrived are still speculative. From post-K/T boundary *Guembelitra* blooms in sections around the world we know that these blooms occurred in shallow and deepwater environments, near shores and in the open ocean, at high and low latitudes. *Guembelitra* blooms are therefore not specific to temperature, water depths, or salinity, but seem to occur during times of low productivity, eutrophic waters, and disruption of normal water mass stratification. For example, the post-K/T *Guembelitra* blooms are invariably associated with a productivity crash as indicated by the drop in surface  $\delta^{13}\text{C}$  to below benthic values (Zachos et al., 1989), but nutrient-rich eutrophic conditions as indicated by the high total organic contents.

Similarly, the late Maastrichtian (zones CF3–CF1, 66.8–65.4 Ma; Fig. 5) *Guembelitra* blooms at Qreiya are associated with a major breakdown in primary productivity, as well as the near absence of tropical ecological specialists. The highest *Guembelitra* abundances are associated with the lowest planktic  $\delta^{13}\text{C}$  values indicating their surface habitat, whereas low abundances are associated with increased  $\delta^{13}\text{C}$ , peak abundances of the biserial *Heterohelix navarroensis* in CF3, and several small biserial species in CF1 (*H. navarroensis*, *H. dentata*, *H. planata*, *H. globulosa*), as well as an increase in rugoglobigerinids (Fig. 5). All of these species are subsurface dwellers living above the thermocline. Carbon isotopes thus suggest that the main factor controlling the impoverished late Maastrichtian planktic assemblages in central Egypt is low primary productivity.

The paleoecology of the triserial *Guembelitra cretacea* is still poorly understood. Kroon and Nederbragt (1990) suggested that it is an upwelling species, based on a triserial species that lives in upwelling areas of the Indian Ocean today. However, no upwelling areas have been associated with late Maastrichtian, or early Tertiary, *Guembelitra* blooms to date. In central Egypt, these blooms occurred in a basin with restricted circu-



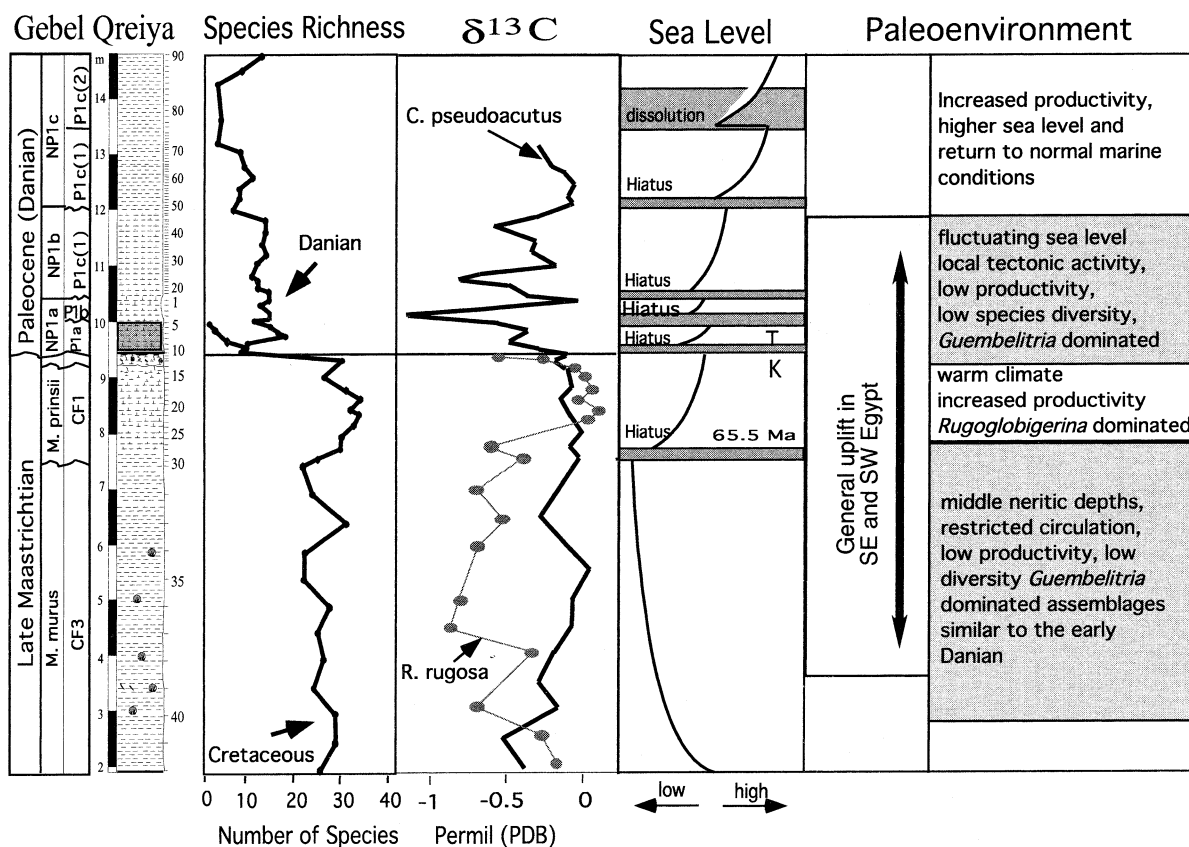


Fig. 6. Summary of paleoenvironmental proxies at Qreiya, Egypt. Note that species richness during the late Maastrichtian is only about half that of normal marine environments, probably as a result of the very low productivity similar to the post-K/T environment. Low productivity in the late Maastrichtian in southern Egypt is associated with tectonic activity, increased runoff of terrigenous detritus including organic matter, a lower sea-level, and probably a restricted basin, eutrophic waters and disrupted thermohaline circulation.

lation, and in southern Tunisia, they occurred in a very shallow marginal environment with salinity and nutrient fluctuations (Keller et al., 1998; Adatte et al., 2002a).

*Guembeltria* species appear to have been surface dwellers, as is suggested by their consistently common occurrences in shallow waters (e.g. Texas, Alabama, Denmark, Tunisia; Keller, 1989; Olsson and Liu, 1993, Keller et al., 1993, 1998, 2002), small size, very light carbon isotopic values, and near absence in normally stratified deeper water environments. However, *Guembeltria* blooms are present in shallow and deepwater post-K/T environments that are characterized by eutrophic conditions (high total organic carbon),

but low productivity. This association with low productivity may reflect: (a) higher tolerance for environmental stress and particularly eutrophic environments; (b) reduced habitat competition following the disappearance of ecological specialists; (c) the advantage of small size and surface dwelling habitat; or (d) a combination of reduced competition and eutrophication favoring small surface dwelling species. The generally inverse relationship with heterohelicid abundances may be related to variations in productivity, oxygen content of waters, and niche competition. At least some Cretaceous heterohelicids (e.g. *Heterohelix globulosa*, *H. navarroensis*, *H. dentata*), as well as early Danian biserial species (e.g. *Woodringina*

*hornerstownensis*, *W. claytonensis*) appear to have been low oxygen tolerant (Boersma and Premoli Silva, 1989; Barrera and Keller, 1994). Although current data strongly suggest that *Guembelitra* blooms are associated with highly eutrophic, but low productivity environments, whether in shallow or deeper waters, further studies of their occurrences in late Maastrichtian sediments are needed to conclusively determine their ecological associations.

## 15. Summary and conclusions

During the late Maastrichtian zone CF3 (66.8–65.5 Ma) central Egypt experienced the critical high stress conditions that are usually associated with the K/T boundary impact event. Surface productivity dropped resulting in an inverse surface-to-deep gradient, species diversity dropped to less than half of normal Tethyan assemblages, and the opportunistic species *Guembelitra*-dominated (60–90%), though alternating with low oxygen tolerant heterohelicids (*H. navarroensis*, *H. dentata*, *H. globulosa*; Figs. 5 and 6). The conditions that created this high stress environment are likely related to local tectonic activity coupled with climate, productivity and sea-level fluctuations. Sediment deposition occurred in middle to outer neritic (100–250 m) environments, interrupted by erosion due to sea-level regressions (Fig. 6). However, similar paleodepth environments in Texas, Tunisia, Israel and the Sinai retained more normal species diversity and *Guembelitra* species are rare or absent, except in two short intervals in the Negev which are marked by syntectonic activity (Almogi-Labin et al., 1990; Abramovich et al., 1998).

In central Egypt, local tectonic conditions coupled with a low sea-level may have temporarily isolated this region and disrupted normal thermohaline circulation. In the south of Egypt, the late Maastrichtian (zone CF3; Fig. 6) coincided with the onset of tectonic activity (Soliman et al., 1986; Hendriks et al., 1987; Hendriks and Luger, 1987; Smith et al., 1994; Schnack and Luger, 1998). The development of uplifted areas may have created a semi-restricted basin with

sluggish circulation, whereas the increased terrigenous runoff supplied high organic matter leading to eutrophic waters. This may have resulted in decreased surface productivity and low species diversity that favored low oxygen tolerant heterohelicids and ecological opportunists. The similarity of these late Maastrichtian assemblages with post-K/T impact assemblages reveals that the planktic foraminiferal response to the K/T catastrophe was not unique, but followed a predictable pattern of response to a specific set of environmental conditions that may or may not be related to impact events.

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