Planktonic foraminiferal biostratigraphy and quantitative analysis during the Campanian-Maastrichtian transition at the Oued Necham section (Kalâat Senan, central Tunisia)

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Abstract: The Oued Necham (ON) section (Kalâat Senan, central Tunisia) provides a well-exposed outcrop of a Campanian-Maastrichtian series that consists essentially of chalky limestones (i.e. the Abiod Formation) grading progressively to a marly unit (i.e. the El Haria Formation). The transitional Abiod-El Haria succession comprises a rich hemipelagic-pelagic fauna in the study area, but ammonites (e.g., *Pachydiscus neubergicus*, the Campanian/Maastrichtian (C/M) boundary index taxon) are scarce to absent, thus preventing the recognition of the standard zones defined for the Tethyan realm. However, the rich planktonic foraminiferal taxa of the El Haria Formation allow us to establish an accurate biostratigraphical scheme. Accordingly, this work presents a high-resolution planktonic foraminiferal biostratigraphy that is characterised by distinct bioevents associated with the reported C/M boundary (i.e. lowest occurrences (LOs) of *Rugoglobigerina scotti* and *Contusotruncana contusa*) at the Global Stratotype Section and Point (GSSP) of the Tercis-les-Bains section, south-western France. Based on these zonal markers, the rugoglobigerinids and multiserial heterohelicids are used to define a subzonal scheme spanning the standard *Gansserina gansseri* Zone, including the *Rugoglobigerina rotundata* Subzone indicative of the late Campanian and the *Rugoglobigerina scotti* Subzone and the *Planoglobulina acervulinoides* Subzone, respectively, indicative of the early Maastrichtian. The abundance of foraminiferal assemblages allowed us to carry out high-resolution quantitative analyses that document a significant climate cooling during the early Maastrichtian intermittent with short-term warming episodes. Thus, opportunist taxa (r strategists, mostly heterohelicids) thrived during the earliest Maastrichtian cooling event, whereas specialist taxa (k strategists, mostly double-keeled) that had dominated the late Campanian assemblages declined gradually without any extinction. Opportunist and specialist taxa fluctuated in opposite phases throughout the early Maastrichtian (LO of *Rugoglobigerina scotti* – LO of *Abathomphalus mayaroensis*), suggesting essentially variations in water temperature. Since surface dwellers dominated the assemblages, they imply continuous sea surface optimal conditions of nutrient supply and water connectivity induced from upwelling currents.

Key words: Campanian/Maastrichtian boundary, planktonic foraminifera, high-resolution biostratigraphy, bioevents, central Tunisia, *Rugoglobigerina scotti* Subzone, *Planoglobulina acervulinoides* Subzone

1. Introduction

The Campanian/Maastrichtian (C/M) boundary has traditionally been placed at the top of the *Radotruncana calcarata* Zone (Herm, 1962; Bolli, 1966; Postuma, 1971; Van Hinte, 1976; Sigal, 1977; Saïd, 1978; Salaj, 1980; Bellier, 1983; Robaszynski et al., 1984; Caron, 1985; Rami et al., 1997; Li and Keller 1998b; Li et al., 1999). According to the integrated biostratigraphical data (using ammonites, inoceramids, calcareous nannofossils, planktonic and benthic foraminifera) formally defined at the Tercis-les-Bains section, south-western France (Global Stratotype Section and Point (GSSP) for the C/M boundary) during the Second International Symposium on Cretaceous Stage Boundaries in Brussels in 1995 (Odin, 2001), the base of the Maastrichtian is no longer defined

by the *Radotruncana calcarata* highest occurrence (HO), but is henceforth characterised by the lowest occurrence (LO) of the ammonite species *Pachydiscus neubergicus* (Odin, 2001; Odin and Lamaurelle, 2001; Ogg and Ogg, 2004). This bioevent coincides at the C/M boundary GSSP with the LOs of the planktonic foraminiferal species *Rugoglobigerina scotti* and *Contusotruncana contusa*. Hence, we hypothesised that the LO of *Contusotruncana contusa* could be concurrent with the LO of *Rugoglobigerina scotti*, as reported at the GSSP Tercis section for the C/M boundary (Arz and Molina, 2001).

A previous integrated biostratigraphy for the late Cretaceous series in the Kalâat Senan area, central Tunisia, by Robaszynski et al. (2000) used several taxonomic groups (e.g., ammonites, inoceramids, planktonic foraminifera,

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and calcareous nannofossils). The study included the El Kef (Fournié, 1978), Abiod, and El Haria Formations (Burollet, 1956) to specify Turonian-Maastrichtian stages' boundaries. Nevertheless, little attention was given in that study to a number of key planktonic foraminiferal species (e.g., *Globigerinelloides* spp., small biserial heterohelicids), which are significant taxa useful for assessing biostratigraphic and palaeoecologic conditions (Arz, 1996; Li and Keller, 1998b; Hart, 1999; Arz and Molina, 2001, 2002; Petrizzo, 2002). Thus, in the absence of the ammonite index taxon and in order to better characterise the C/M boundary in the same area, the present work aims to provide a high-resolution stratigraphic range of the planktonic foraminiferal group during this transition interval. The study focuses specifically on reliable index taxa that are used as "zonal and subzonal marker species" to define the new proposed subzones. Hence, the new detailed subzonation of the standard *Gansserina gansseri* Zone (Brönnimman, 1952; Robaszynski et al., 1984; Robaszynski and Caron, 1995; Arz, 1996; Robaszynski et al., 2000; Arz and Molina, 2002) involves the consecutive origination of rugoglobigerinids and multiserial heterohelicids. The new subzones also correlate with the previously proposed zonal schemes for the Tethyan realm.

In addition to their biostratigraphic value, planktonic foraminifera can be useful indicators to further highlight extant environmental conditions. In fact, their relative abundances are documented to be closely related to abiotic ecosystem parameter changes (Arz, 1996; Li and Keller, 1998b; Hart, 1999; Arz and Molina, 2001, 2002; Petrizzo, 2002; Abramovich et al., 2003, 2010). Therefore, their temporal fluctuations are considered as adaptive responses to either coping with or benefiting from climatic and/or environmental changes (Arz, 1996; Li and Keller, 1998b; Hart, 1999; Arz and Molina, 2001, 2002; Petrizzo, 2002; Abramovich et al., 2003, 2010). It has been shown that multiple environmental factors can have remarkable effects on the evolution of their test morphology and ornamentation, depending on the degree of the forcing factors (Arz, 1996; Li and Keller, 1998b; Hart, 1999; Arz and Molina, 2001, 2002; Petrizzo, 2002; Abramovich et al., 2003, 2010). Therefore, a semiquantitative analysis of species, genera, morphotypes, and morphogroups was also carried out in order to detect the main bioevents and potential faunal turnover that could have affected planktonic foraminifera in Oued Necham throughout the Campanian-Maastrichtian transition. Moreover, planktonic/benthic (P/B) ratios were calculated in an attempt to reconstruct the depositional environment in the studied area.

## 2. Geological and stratigraphical settings

The Oued Necham section is located in the Kalâat Senan area, central Tunisia, close to the Tunisian-Algerian border (Figure 1), ~50 km south of El Kef and ~3 km ESE of Aïn Settara.

Geologically, the Kalâat Senan area extends over the south-eastern side of a NE-SW trending Cretaceous-Eocene syncline (Figure 1), which belongs to the Central Tunisian Atlassic domain (Castany, 1951). As a part of the southern margin of the Palaeo-Tethys (Figure 2) during the Cretaceous, the north-western segment of this structural unit acted as connected deep basins known as the "Tunisian trough", which was characterised by subsidence and sediments rich in pelagic fauna (Burollet, 1956; Salaj, 1980; Turki, 1985; Maamouri et al., 1994; Rami et al., 1997; Robaszynski et al., 2000; Steurbaut et al., 2000; Bouaziz et al., 2002; Jarvis et al., 2002; Hennebert and Dupuis, 2003; Zaghbib-Turki, 2003; El Amri and Zaghbib-Turki, 2005; Guasti et al., 2006; Hennebert et al., 2009). Among the sediments that were deposited within the trough area, those that are now exposed at the Oued Necham section (with the geographical coordinates X = 35°46′28.3″N and Y = 8°28′55.7″E) provide a coherent and continuous Campanian-Maastrichtian transition.

In northern and central Tunisia, the Campanian-Maastrichtian transition encompasses the upper part of the Abiod Formation (Fm.) and the lower part and of the El Haria Fm., both defined by Burollet (1956). The Abiod and the El Haria Formations are respectively characterised by chalky limestone and dark grey marls rich in pelagic fauna (Burollet, 1956), displaying a quite progressive lithologic transition change in Kalâat Senan. Burollet (1956) subdivided the Abiod Fm. into three members: a lower micritic limestone unit overlain by an intermediate member of interbedded limestones and marls, which is capped by an upper limestone unit (Figure 3). Detailed analysis of lithostratigraphic and facies changes of the Abiod Formation in the study area allowed Robaszynski et al. (2000) to recognise seven successive members: Assila, Haraoua, Mahdi, Akhdar, Gourbeuj, Necham (NCH), and Gouss, respectively (Figure 3). These proposed seven units were also identified in Elles, north-western Tunisia (Robaszynski and Mzoughi, 2010). The initial tripartite Abiod Formation was also differently subdivided into seven lithological units by Bey et al. (2012) at Aïn Medheker, north-eastern Tunisia.

Further lithofacies analysis of the studied Oued Necham section allowed the distinguishing of six units from A to F in the basal part of the El Haria Fm. (Figure 3). The first unit (A) spans ca. 7 m (samples ON 200-4–ON 209) and corresponds to the Gouss member (Robaszynski et al., 2000), which is dominated by inoceramid-rich limestones. The other succeeding units, Units B, C, D, E, and F, are mostly marly and are distinguished depending on their content of limestone beds. The present work pays particular attention to the transitional NCH and Gouss
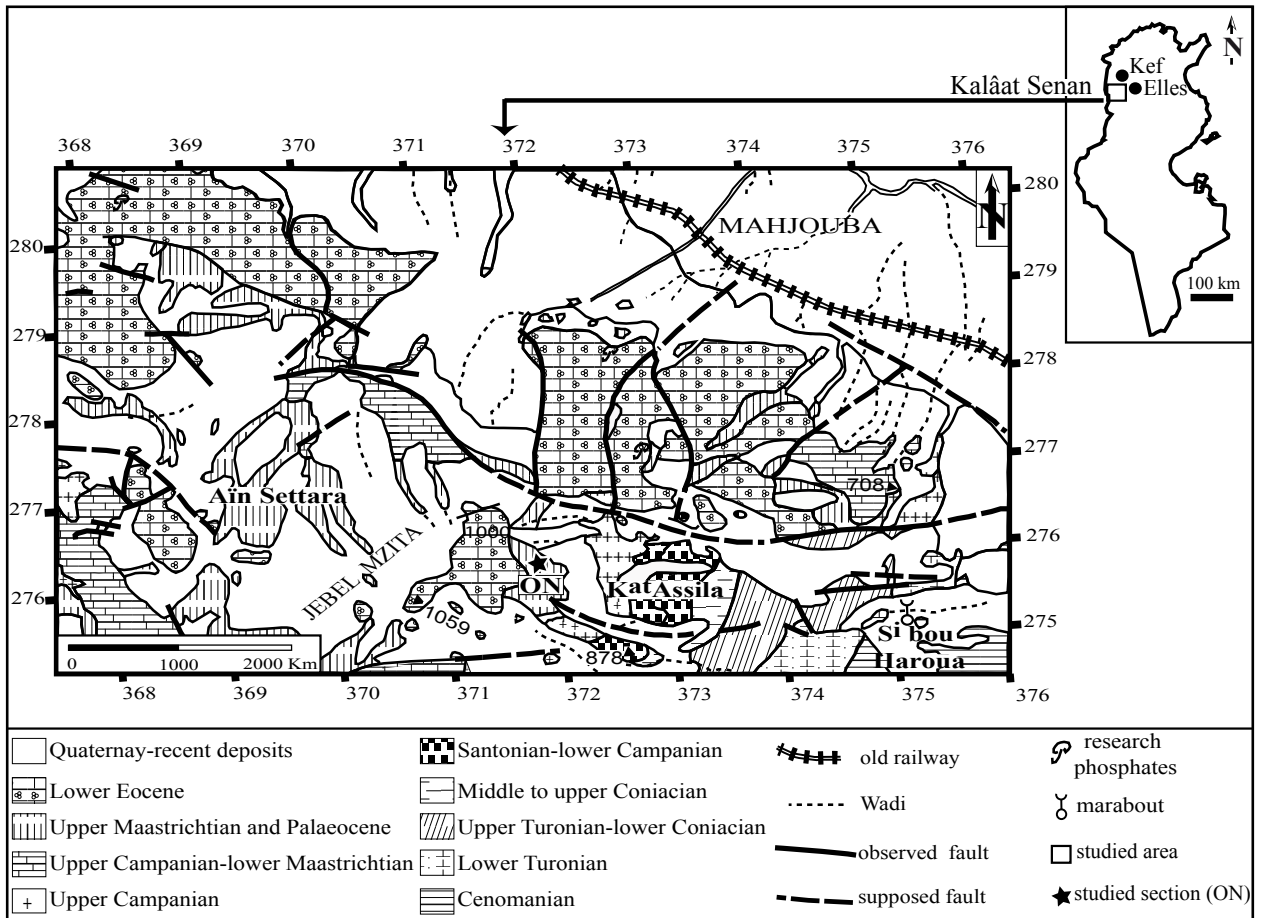
Figure 1. Location of the Oued Necham section on the extract map portion from the geological map of the Kalâat Senan region, n° 59 at a 1/50,000 scale (Lehotsky et al., 1978, simplified).

members between the Abiod and the El Haria Formations because the LO of *Contusotruncana contusa* had been reported at NCH 225 by Robaszynski et al. (2000, p. 378, figure 8d).

3. Materials and methods

High-resolution sampling was done to analyse planktonic foraminiferal assemblages from the transitional Gouss member (Unit A) between the Abiod and El Haria Formations and the overlying basal part of the El Haria Fm. (Units B–F) in order to accurately refine the C/M boundary and obtain suitable quantitative data. Therefore, a total of 95 samples were taken from the 95-m-thick studied section (Figure 4).

The initial sampling was planned with a spacing of 50 cm for the 8 m below and ~6 m above the reported NCH 225 level of Robaszynski et al. (2000) and a spacing of 1 to 2 m beyond this level. Preliminary observations of the samples revealed (Figure 4) the successive order of the occurrence of typical *Rugoglobigerina scotti* specimens in the lower part of the section (ON 211; Unit

B) and *Planoglobulina acervulinoides* and *Abathomphalus mayaroensis* in the upper part of the section (ON 271.5 and ON 290, respectively; Unit F). Based on these findings, additional samples were collected at intervals of 10–30 cm in the lower and upper parts of the section (under ON 211 and above ON 290) to provide a more robust data set in search of the LOs of the index taxa that define the early and late Maastrichtian boundaries (Figure 4).

In the laboratory, 500 g from each sample was washed through a set of Afnor sieves (63–500 μm), dried in oven at a temperature below 50 °C, and then sorted for picking out typical foraminifera.

Focusing on the Campanian-Maastrichtian biostratigraphy, planktonic foraminiferal occurrences were carefully examined throughout the studied section. Thus, species were identified under a stereomicroscope keeping in consideration the existence of intermediate evolutionary forms. Taxonomic identification was carried out using the online catalogue of Ellis and Messina (1940) and mainly the works of Robaszynski et al. (1984), Caron (1985), Nederbragt (1991), and Arz (1996), as listed in
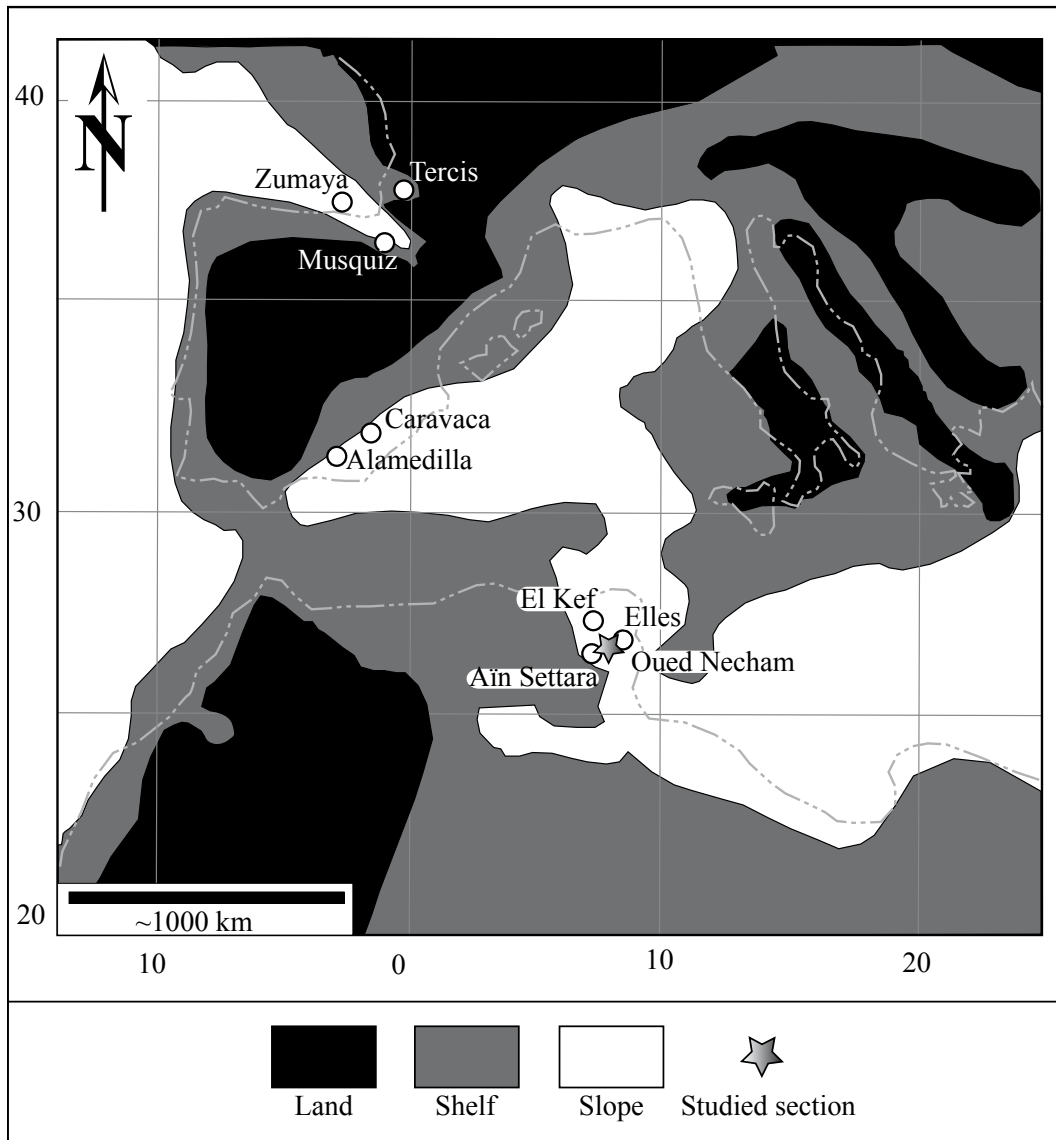
Figure 2. Maastrichtian palaeogeographic setting of the studied area and other sections (Denham and Scotese, 1987, modified by Arz and Molina, 2002, simplified).

detail in the Appendix. Selected specimens and zonal/ subzonal marker species were photographed using a scanning electron microscope.

With the main goal of determining the unique planktonic foraminiferal characteristics during the C/M transition, a standard Otto microsplitter was used to split five fractions for each sample to carry out a semiquantitative analysis. Accordingly, at least 300 planktonic foraminifers were selected from each sample split. The same number or more was considered for P/B ratio calculation from the fraction of ≥100 μm. Data of the specimens' counts are presented in Tables 1–3 and the relative abundance curves of selected species, morphotypes, and morphogroups are plotted against the stratigraphic succession.

4. Results
The studied section is rich in pelagic fauna, but ammonites are very rare as only one level yielded a *Haploscaphites* sp. specimen (i.e. sample ON 269, Unit E; middle part of the Oued Necham section, Figures 3 and 4). In contrast, planktonic foraminiferal assemblages are highly diversified and allowed identification of several bioevents. Therefore, the lower part of the studied section (Unit B, sample ON 211-5) includes the LOs of both *Rugoglobigerina scotti* and *Contusotruncana contusa*, just above the inoceramid-rich limestone beds of the underlying Unit A (Figure 4). These LOs were initially correlated with an age of −72 ± 0.5 Ma (Arz, 1996; Odin, 2001; Odin and Lamaurelle, 2001; Arz and Molina, 2002) and subsequently astronomically
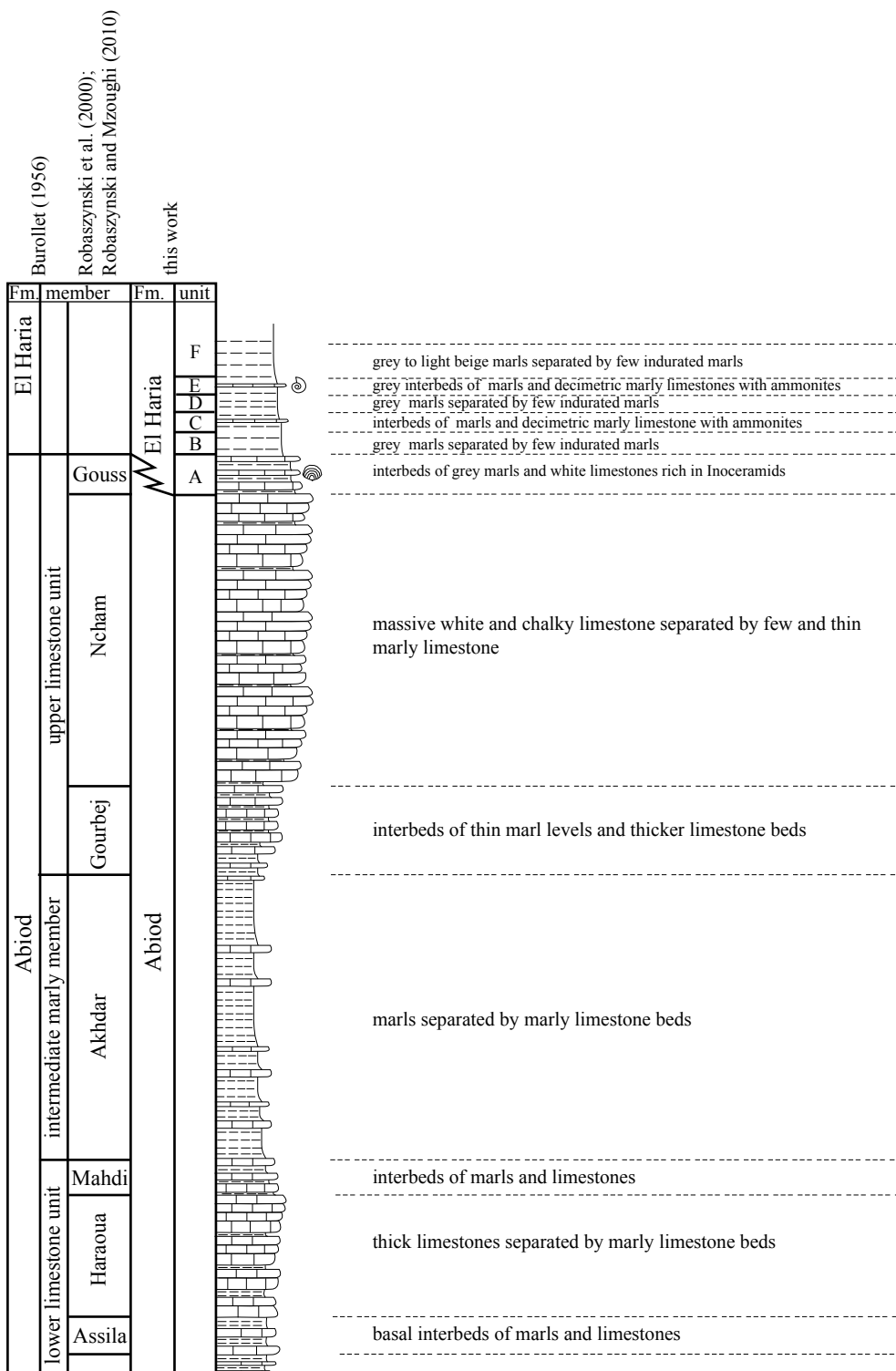
Figure 3. Lithostratigraphic succession of the Abiod-El Haria transition in Kalâat Senan. Lithofacies is inspired by Robaszynski et al. (2000), simplified. Fm. = Formation.
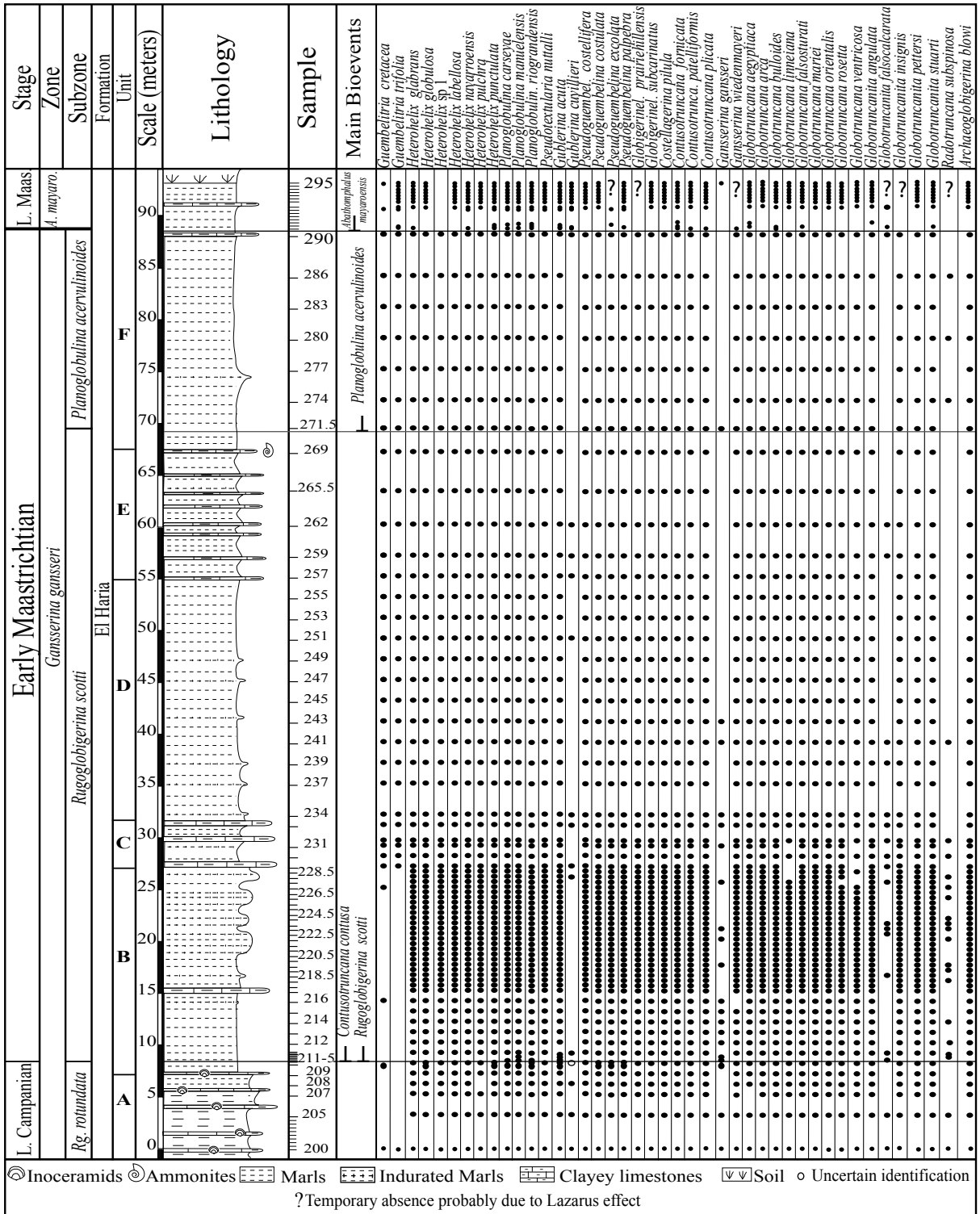
Figure 4. Stratigraphic distribution of planktonic foraminiferal species throughout the Campanian-Maastrichtian transition interval at the Oued Necham section.
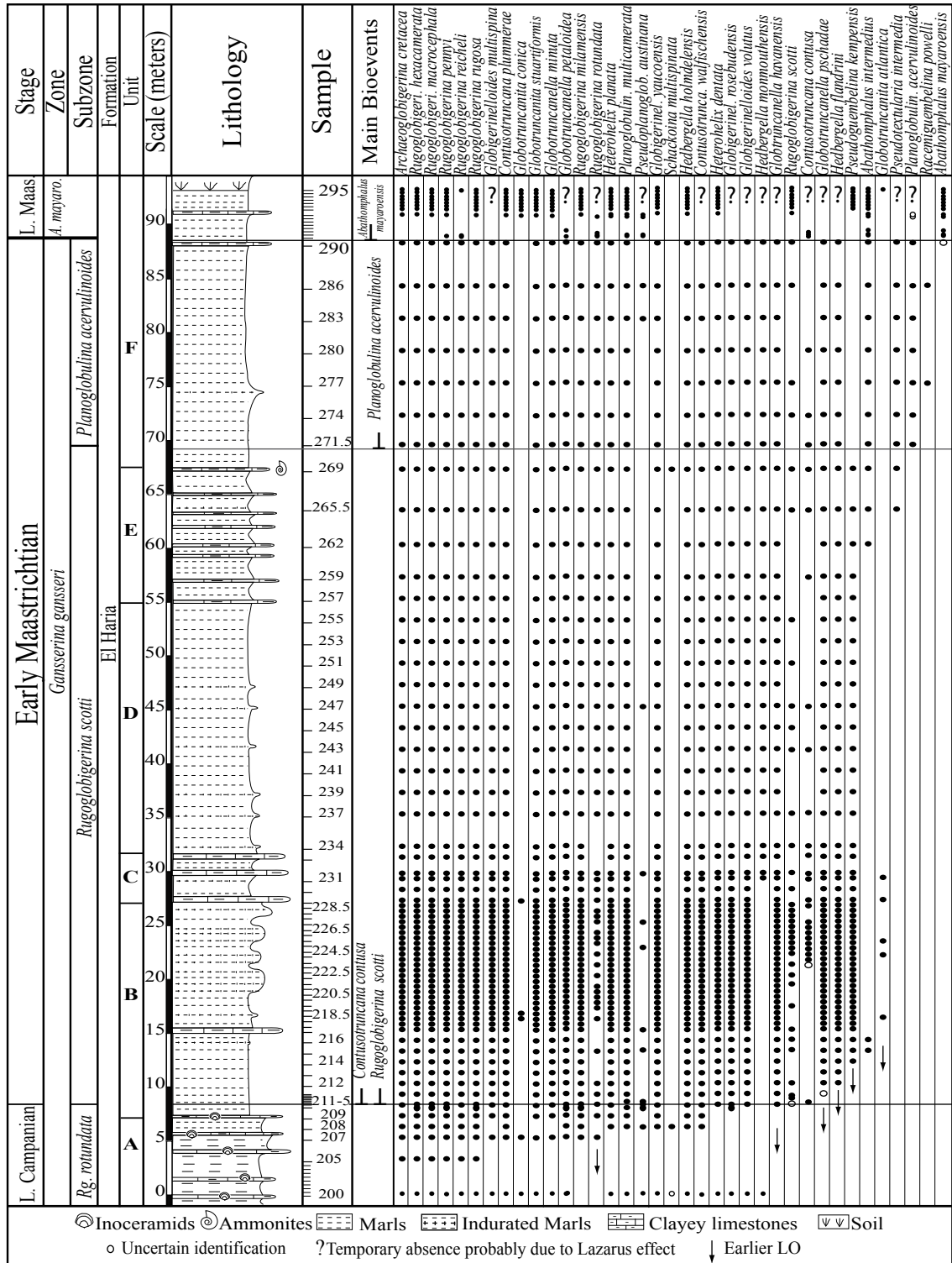
Figure 4. (Continued).

Table 1. Relative abundance data of planktonic foraminifera from the Oued Necham section lower part, sample fractions of >63 µm.

Species \ Sample	200-4	205	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224
Abath. intermedius											1	3		2	1	2		3		
Abath. mayaroensis																				
Archaeo. blowi	11	13	16	12	4	10	13	11	4	5	14	4	19	17	4	8	8	13	16	5
Archaeo. cretacea	13	17	44	9	2	11	18	6	1	3	35	14	23	22	8		3	8	17	9
Archaeo. sp.																				
Costellager. pilula		2		2	5	35	12	17	18	22		1		4	4		14	6	7	2
Cont. contusa		0	0	0																
Cont. fornicata	4	7	12	15	6	1		3	3		4	12	4	7	13	9		5	6	14
Cont. patelliformis	1	10	5	8	10		1	4	4	1	1		4	4	6	2		2		6
Cont. plicata		2	20	4	6			2		1	3		2	4	2	4	3	4	6
Cont. plummerae	3		11	11	11	2	2	10	7	3	7	4	5	5	4	7	4	10	10	10
Cont. walfishensis																				
Cont. sp.	1	1	0	0		1		1							1					
Gan. gansseri	2	2	0	0		1				1	1	2	2			1				1
Gan. wiedenmayeri	1	8	1	2	3						2		1							2
Gl. multispina	1		1		1	2	2				1			1	1		1	3	1
Gl. prairiehillensis		1	1	2	1	5	3	3	2	1	1			2	1		1		
Gl. rosebudensis	3				5	1	3	7	7	2		1		2	1		2	2	2
Gl. subcarinatus	6		1		1	11	3	3	5	10	7			1	3	4		5	6	6
Gl. volutus	3				6	2	2	3	1		1				4	2		2	1
Gl. yaucoensis	1		2		2	4		2	6	1	1							2	4
Gl. sp.																				
Gna. aegyptiaca	3	3	0	2	5	6	9	23	8	7	9	8		8	6	9	4	4	6	8
Gna. arca	1	11	5	15	30	2	9	22	5		5	3	5	15	10	9	8	4	3	6
Gna. bulloides	12	10	16	43	45	21	38	24	10	8	12	32	11	25	14	12	15	30	19	38
Gna. falsostuarti	3	5	8	4	5		1	7	1		7	4	5	16	2	8	5	2	4	5
Gna. linneiana	2	4	0	1	1		4	3	2		1		5	3	1	4	1	1		1
Gna. mariei	3	23	6	6	12	7	4	6	5	3	1	9		5	8		4	2	2	4
Gna. orientalis	1	17	8	12	11	2	6	3	3		3	1	4	13		5	2	3	5	4
Gna. rosetta		3	3	0	2	1	1				1		2	2	4	1		1	1	
Gna. ventricosa	1	15	7	0	2	2	5	5	6		5	2	3	1	7					4
Gna. sp.	5	8	11	0	9	1		1				1	1	1	2		1			1
Glla. havanensis				0		1		1	1			1	1							
Glla. minuta			1	0		2		1								3	2	2	4	
Glla. petaloidea			2	0		1	2		3	4	2	7	8	2	1	4	6	1	1	2
Glla. pschadae			0	0				1	1	3					1	2			
Glla. sp.			1	0																
Gta. atlantica				0																
Gta. angulata		5	6	2	2			1						3		1	1	1	1	1
Gta. conica		0	1	0												1				
Gta. falsocalcarata		2	0	0			2								1				1	
Gta. insignis		3	4	1	3	1		1			1	1	1		1				1	

Table 1. (Continued).

Gta. pettersi	1	1	6	2			1	2			2					1			1	1
Gta. stuarti		4	3	7			1	2			1	4				1			1	2
Gta. stuartiformis	2	1	7	3	5		2	4	1		1	1	1	2	2		1		1	3
R. subspinosa			0	0	0		1	1								4				
R. cf. subspinosa					2															
Gta. sp.	6			0	1		4								2		1			
Gu. acuta		1	3	0					2		1	1							2	
Gu. cuvillieri			0	0						1										
Gue. cretacea											1						2	3	6	1
Gue. trifolia																		2		1
H. flandrini						1														
H. holmdelensis	5	0	1	0	1		1			1	4	1		7	5	2	2	2		2
H. monmouthensis	1	0	0	0							2									
H. simplex																				
H. sp.					0			1	1											
Hx. dentata	2						1		2	5	5	6	8	4	10	11	3	5	1	
Hx. glabrans	17	2		1		4	4	1	4	4		3	3		3	1	4	1	3	6
Hx. globulosa	17	10	16	25		30	25	12	27	26	17	30	15	31	37	48	50	39	53	31
Hx. sp. 1		1	9	6		4	6	4	4	4								2	4	3
Hx. spp.	31	3	8	31	8	2	4	12	6	22	16	18	31	6		2	15	2	7	6
Hx. labellosa		10	3	11	1	15	4	6	7	4	6	16	2	6	8	18	12	5	16	20
Hx. navarroensis	45	4	5	14		35	26	15	22	32	33	20	27	29	20	27	30	41	27	38
Hx. planata	17			2	1	3	2			15	15	1	1	6	7	10	17	16	15	18
Hx. pulchra	2	1	3			2	3	2	5	7	1		4	3	1	5	4	3	1	
Hx. punctulata	1	8	19	14	26	2	2	4	9	4	9	25	17	1	17	9	12	14	4	20
Pl. acervulinoides																				
Pl. carseyae				1			1		2				1	1			1			
Plano. manuelensis		2	1	1	1		1			1					1		1	1		1
Plano. multicamerata																				
Plano. riograndensis	1		1				1				1					2				1
Planoglobulina sp.			1								1									
Pseudog. costellifera	5	4	2	1	4	6	7	20	21	7	4		1	11	8	2	5	3	2	
Pseudog. costulata	9	10	9	0	1	8	6	9	16	36	24	12	17	14	14	8	17	18	11	16
Pseudog. excolata	1			6		4	4	3			1		2	2	1	1			2	4
Pseudog. kempensis										4			1							
Pseudog. palpebra		1	3	3	3	3	17	6	16	13	3	1		6	13	3	3	3	4	2
Pseudog. sp.	10			0					8	5	6	11	1	3		1	1	1		
Pseudop. austinana				0												1				
Pseudotex. intermedia																				
Pseudotex. nuttalli	11	17	46	27	22	8	18	9	23	12	17	15	13	18	37	35	20	21	24	31
Pseudotextularia sp.																				
Pseudotex. elegans												1	1	1	1					
Rg. hexacamerata	4	11	3	9	4	10	16	11	14	3	10	17	3	16	5	5	13	4	2	10

Table 1. (Continued).

Rg. macrocephala	5	4	1	1	1	4	9	3	8	7	1	6		2	2	2	10	1		3
Rg. milamensis		1		1	5		3	3	2	2	8	1	1		1			4		5
Rg. pennyi	3	7	3	3	2	3	3	5	2		1	6		2	1	9	4	8	1	3
Rg. reicheli	1	2				1	1	2	1					4		5	8	2	2	1
Rg. rotundata			2		5		1	1	1		1		1			1	6			1
Rg. rugosa	13	23	11	13	22	26	29	13	14	15	6	13	7	3	24	32	13	19	13	9
Rg. rugo-hexacam.					2		1	1												
Rg. rugo-macroceph.						1	2													
Rg. scotti							3			1	3		2		1			9	3	2
Rg. sp.	10	4		6	6	8	6	4	7	2	8	3	36		4	3	3	2	4	2
Schack. multispinata	2									0										2
Counted specimens*	303	304	357	341	300	315	356	319	316	317	331	329	303	331	336	349	350	338	345	392
Counted foraminifers for P/B ratio**	304	301	302	302	301	320	303	317	313	314	300	300	300	301	301	304	304	300	309	300
Counted planktonic specimens**	273	269	288	292	288	302	287	303	295	299	277	283	279	269	291	277	285	266	297	272

*Total of planktonic species specimens from sample splits.
**Counted planktonic and benthic specimens from each sample split differently from counted planktonic specimens.

calibrated by Husson et al. (2011) to an age between –72.34 and –72.75 Ma integrated within the C32n2n Chron, in agreement with Lewy and Odin (2001), Odin and Lamaurelle (2001), Arz and Molina (2002), Odin (2002), Gardin et al. (2012), Cohen et al. (2013), and Batenburg et al. (2014). However, Thibault et al. (2012, 2015) recognised a slightly younger age of –72.15 ± 0.5 Ma for the boundary.

The LO of *Planoglobulina acervulinoides* is observed in the upper part of the section (Unit F, sample ON 271.5, Figure 4), thus corresponding to an approximate age of –71 to –70 Ma included within the C 31 Chron (Arz and Molina, 2002). The uppermost part of the section comprises essentially decimetric limestone beds and includes the LO of *Abathomphalus mayaroensis* (uppermost part of Unit F, sample ON 292, Figure 4), thereby correlative with an age of –68.3 Ma (Ogg and Ogg, 2004) included within the C31 Chron (Arz and Molina, 2002; Ogg and Ogg, 2004).

4.1. Biostratigraphy
During the Second International Symposium on Cretaceous Stage Boundaries in Brussels in 1995, it was formally recommended and accepted that the LO of *Rugoglobigerina scotti* constitutes one of the reported bioevents to mark the C/M boundary (Arz, 1996; Arz and Molina, 2001; Odin, 2001; Arz and Molina, 2002; Odin, 2002) at its GSSP, the Tercis-les-Bains section (France). The foraminiferal bioevent coincides with the LO of the ammonite species *Pachydiscus neubergicus* among 11 other identified bioevents defined by ammonites, inoceramids,

dinoflagellates, calcareous nannofossils, and planktonic and benthic foraminifera species, respectively (Odin, 2001).

Using the identified planktonic foraminiferal criteria (e.g., *Rugoglobigerina scotti* and *Contusotruncana contusa*), the C/M boundary in the Oued Necham section is newly specified without any apparent stratigraphic hiatus. Thus, *Rugoglobigerina* and *Planoglobulina* phylogenetic evolutions permit the establishment of a detailed subzonation spanning the upper part of the *Gansserina gansseri* Zone in the studied section. Accordingly, three subzones are proposed as follows: the *Rugoglobigerina rotundata* Subzone correlative with the late Campanian, followed by *Rugoglobigerina scotti* and *Planoglobulina acervulinoides* Subzones, respectively, which encompass the early Maastrichtian.

Brönnimann (1952) initially defined the *Gansserina gansseri* Zone as the interval range zone (IRZ) between the LO of the nominate taxon and the LO of *Abathomphalus mayaroensis*. According to Arz and Molina (2002), its duration is ~4 Ma (from –73 Ma to –69 Ma) and it coincides with C32 and C31 Chrons (Arz and Molina, 2002; Ogg and Ogg, 2004).

4.1.1. *Rugoglobigerina rotundata* Subzone
Arz (1996) defined the *Rugoglobigerina rotundata* biozone as an IRZ that spans the interval between the LO of the nominate species and the LO of *Rugoglobigerina scotti*. According to several authors in the published literature,

Table 2. Relative abundance data of planktonic foraminifera from the Oued Necham section middle part, sample fractions of >63 µm.

Species \ Sample	225	226	227	228	228.5	229	230	231	233	234	237	239	241	243	245	247	249	251	253	255
Abath. intermedius		3						1	1					3				2	4	2
Abath. mayaroensis																				
Archaeo. blowi	8	9	10	14	7	12	8	18	1		5	14	3	15	2	8	11	2	3	2
Archaeo. cretacea		1	8	10	5	6	16	7	3	5	5	12	9	11	1	8	7	2	2	
Archaeo. sp.	1				2															
Costellager. pilula	8	9	8	9	9	1	13	9	3	5	20	14	1	2	11	8	21	6		7
Cont. contusa				1			0									1				
Cont. fornicata	5	3	8	7	3	15	12	4	10	4	2	3	15	13	3	6	3	10	9	12
Cont. patelliformis	1	3	5	3	7	3	7		8		1		2	6	1	3	1	3	3	6
Cont. plicata	6	3	7		2	0	1	2			1	3	1		3	1				3
Cont. plummerae	4	8	7	8	9	11	7	6	17	16	3	10	28	13	13	11	10	19	32	18
Cont. walfishensis													1							
Cont. sp.	1				2	1	0					1		2						
Gan. gansseri		1	0	2			0	1	1	1			3	1						
G. wiedenmayeri		0					0	1												
Gl. multispina	1		1	2		1	1	1			2	1	1	2	1					
Gl. prairiehillensis			5	4		1	3	1	5	1		5	2	1	2		3	4	2	
Gl. rosebudensis		2	2	3	1	1	2			1	1	2	2	4	4			4	2	
Gl. subcarinatus	5	14	4	6	7	2	4	4	5	5	15	5	2	5	5	6	10	6	3	5
Gl. volutus	1	4	1	2	2	3	5			1	5	8	4	10	3	3	2	3	1	2
Gl. yaucoensis		6	2	1	2	1	1	1	1	1	1	5	5	3	13	7	5	5	3	1
Gl. sp.			1			11		1				1								
Gna. aegyptiaca	10	6	5	14	4	17	1	3	6		5	2	3	3	5	3	6	20	5	8
Gna. arca	8	7	12	10	10	35	8	14	11	15	4	5	10	8	5	2	4	7	8	2
Gna. bulloides	30	20	17	33	23	2	23	25	25	17	18	25	74	37	11	54	17	32	33	16
Gna. falsostuarti	1	2	1	1	2		3	4	9	6	2	1	7	3	3		2	2	1	1
Gna. linneiana		3	0	3		3	0				1	1	2		2			7	2	1
Gna. mariei	6	2	7	5	1		6	3	13	6	1	1	1	6	1	1			4	3
Gna. orientalis	5	1	8	3	2	5	0		5	2			2	2	1		2	2	2	2
Gna. rosetta	4	2	1			4	0	2	2	4			1		1	1	2	3	1	
Gna. ventricosa		1	2		1		0		1	2			1	1		1		2	1	2
Gna. sp.			6			2	0	2	1	1	1								1	1
Glla. havanensis		2		1		1	1						1					1		
Glla. minuta		2	0	3		2						1	1	1				1		
Glla. petaloidea	2	1	3	2		1	2		2			1	2	3	2	4	1		2	2
Glla. pschadae	1		0		1		0			1						1				
Glla. sp.			0				0													
Gta. atlantica			0			1	0	1												
Gta. angulata	2	3	0	2		1	0	3	1	1			3	2		1				
Gta. conica			0			1	0													
Gta. falsocalcarata				1		3	1	1	1	1		1	1				1			
Gta. insignis			0			3	1	1	2				2	2		2	2		1	

Table 2. (Continued).

Gta. pettersi	2		0	1		2	0		2	1			2	1			1			
Gta. stuarti	1		3	1	2	4	2	1		2	1	2	2	1				2	1	2
Gta. stuartiformis	1	5	1	6	3	4	1	5	9	4	1		3	3	2	2	1	2		
R. subspinosa			0			2							3							
R. cf. *subspinosa*																				
Gta. sp.		1	2	1	1	5	0			1										
Gu. acuta	3	1	4	2			1		4		2				1		1	3	3	3
Gu. cuvillieri					1	0		4	1									2		
Gue. cretacea	1	1	1		1		0	1			8	3	6	14	2	1		3	3	
Gue. trifolia			1								3		1	1	2			1	3	
H. flandrini																		1		
H. holmdelensis		4	1	3	1		1	1			1		2		3	4	4	6	4	
H. monmouthensis			1				0	1										3	2	6
H. simplex																				
H. sp.							0		1		1									
Hx. dentata		1	6	2	3		1	2	1	2	2	12		5	5	4	4	3	1	4
Hx. glabrans	6	9	11	5	3	1	7	4	5	8	9	4	2	4	2	1	4	2		2
Hx. globulosa	36	44	48	87	37	33	46	55	50	62	45	64	22	21	45	37	30	30	21	16
Hx. sp. 1							0	3		3	4		4	1	6	6				1
Hx. spp.	3	5	18	15	13	12	17	23	10	10	9	38	27	42	9	17	14		1	17
Hx. labellosa	7	12	14	10	7	8	15	12	10	6	10	23	7	13	12	21	13	8	4	2
Hx. navarroensis	19	19	34	26	50	33	42	63	32	36	34	36	16	26	55	38	42	18	24	28
Hx. planata	5	14	9	10	9	2	5	5		4	4	18	1	7	23	21	14	23	15	32
Hx. pulchra	1	5	5	2		1	1	3	2	3	3	3		10	5	5	10	3	3	5
Hx. punctulata	23	27	6	6	4	10	11	6	5	10		2	10	7	12	9	9	12	27	18
Pl. acervulinoides																				
Pl. carseyae			1			1					1				2		1	1	1	
Plano. manuelensis		1	4		1	2	0		1	1	1							1	1	
Plano. multicamerata			0				0													
Plano. riograndensis		1			1	1	2	1												
Planoglobulina sp.												1								
Pseudog. costellifera	2	5	5	3	1	1	0	2			3	6	1	14	11	7	4	4	6	2
Pseudog. costulata	11	20	11	7	8	12	17	11	5	5	3	7	4	23	21	32	37	20	28	17
Pseudog. excolata	2		3	1			0		2		1			2	2	5	1	3	3	3
Pseudog. kempensis	1			1												1	1	4	4	1
Pseudog. palpebra	6	5	6	3	2	1	5	3	1	8	2	2	3	4	7	4	2	2	11	2
Pseudog. sp.	1		8	1	1	1	1	6	4	2	3	2	1						3	4
Pseudop. austinana							0											1		
Pseudotex. intermedia			0				0													
Pseudotex. nuttalli	36	21	34	25	9	10	36	7	29	32	23	18	23	22	9	20	24	11	2	15
Pseudotextularia sp.							0													
Pseudotex. elegans					1															
Rg. hexacamerata	25	10	6	1	10		9	3	4	2	14	4	1	4	15	6	4	9	7	7

Table 2. (Continued).

Rg. macrocephala	2	6	3	8	1	1	5	5	2	2	6	1			2	2	3	2	3	3
Rg. milamensis	2		0	1	4	1	6	1	1		5	2	2	1		2	3	4	7	3
Rg. pennyi	4	1	1	2	2		6	5	1	1	2	1		2	1	3		1		3
Rg. reicheli	3	4	1	2	4	1	1	5	2	1	1		2	1			1			
Rg. rotundata		2	1	1		1	2	2	1		2									
Rg. rugosa	25	26	17	5	14	11	25	13	12	8	30	14	6	9	5	7	17	19	16	18
Rg. rugo-hexacam.							0													
Rg. rugo-macroceph.		0																		
Rg. scotti	3	5	3	3	4	1		3	2	1	1		1	3	3		1			1
Rg. sp.	1	1	1	2	7	3	1	2		2	10	4	1		1	1			1	2
Schack. multispinata																				
Counted specimens*	342	371	404	387	308	313	395	371	339	315	325	397	336	394	362	395	357	342	330	323
Counted foraminifers for P/B ratio**	305	315	304	303	303	300	305	300	305	308	302	316	310	300	310	300	360	305	300	300
Counted planktonic specimens**	289	310	287	294	294	283	290	290	289	295	280	303	279	286	264	271	351	282	282	272

*Total of planktonic species specimens from sample splits.
**Counted planktonic and benthic specimens from each sample split differently from counted planktonic specimens.

the LO of *Rugoglobigerina rotundata* slightly postdates the LO of *Gansserina gansseri* (Robaszynski et al., 1984; Arz, 1996; Robaszynski et al., 2000; Arz and Molina, 2002). In this case, the *Rugoglobigerina rotundata* Subzone could be correlated to the lower part of the *Gansserina gansseri* Zone. In Kalâat Senan, the LO of *Rugoglobigerina rotundata* was reported in sample NCH 250 of Robaszynski et al. (2000). In the present work, the LO of *Rugoglobigerina rotundata* was not recorded because this taxon is present in the first (or oldest) sample of the studied section (Unit A; Figures 4–6), therefore prior to sample NCH 250 of Robaszynski et al. (2000). Consequently, Unit A is totally assigned to the upper part of the *Rugoglobigerina rotundata* Subzone.

The nominate index species of this subzone is associated with a diversified number of other taxa such as *Pseudotextularia nuttalli*, *Heterohelix globulosa*, *Globotruncana bulloides*, and *Rugoglobigerina rugosa* (abundant); *Rugoglobigerina hexacamerata* and *Contusotruncana plicata* (common); and species such as *Gansserina gansseri*, *Globotruncanella havanensis*, *Gublerina cuvillieri*, and *Pseudoguembelina palpebra* (less frequent to rare). The association of these species within Unit A (Figure 4) suggests a late Campanian age for the *Rugoglobigerina rotundata* Subzone.

4.1.2. *Rugoglobigerina scotti* Subzone
Masters (1977) initially defined the *Rugoglobigerina scotti* biozone, which was subsequently used by Jansen and Kroon (1987) as an IRZ. It spans the interval between the LO of the nominate species and the LO of *Abathomphalus mayaroensis*. It was also used by Arz (1996) as a zone and subsequently used by Arz and Molina (2002) as a subzone. These authors emended the original definition by using the LO of *Planoglobulina acervulinoides* to define its upper limit rather than the LO of *Abathomphalus mayaroensis*. Here we use the *Rugoglobigerina scotti* Subzone as proposed by Arz and Molina (2002).

The higher-resolution sampling revealed the first occurrence of typical *Rugoglobigerina scotti* in sample ON 211-5 (Unit B, Figures 4 and 5). Similar to several Spanish sections (Arz, 1996), this subzone spans ~60 m covering the interval between samples ON 211-5 and ON 271.5 (Units B to E and the lower part of Unit F). In the Tethyan realm, the base of this subzone can be correlated with the middle part of the standard *Gansserina gansseri* Zone (Figures 4–7) (Arz and Molina, 2001).

The planktonic foraminiferal assemblage of this subzone is slightly different from that of the underlying *Rugoglobigerina rotundata* Subzone as it seems to include no evident extinction and most concurrent species range from the Campanian to throughout the Maastrichtian. Several genera reached their maximum diversification at the base of the subzone, namely taxa of the genera *Rugoglobigerina* and *Contusotruncana*, such as, for instance, the important bioevent characterised by the cooccurrence of *Rugoglobigerina scotti* and *Contusotruncana contusa*. This bioevent was followed, a few meters above, by the

Table 3. Relative abundance data of planktonic foraminifera from the Oued Necham section upper part, sample fractions of >63 μm.

Species \ Sample	257	259	262	266	269	272	274	277	280	283	286	290	295 0
Abath. intermedius	5	2	1							1	1	2	5
Abath. mayaroensis													3
Archaeo. blowi	3	7	4	1	3	10	6	5	4	4	5	4	5
Archaeo. cretacea	5	1	5	4	4	5	3	5	1	15			1
Archaeo. sp.		1	6										
Costellager. pilula	6	13	2	2	1	2				3		13	2
Cont. contusa								1					
Cont. fornicata	13	24	17	16	4	11	5	8	7	10	17	4	32
Cont. patelliformis	1	4	3	11		3	1	5	1	1	1		7
Cont. plicata	2	2	2	5	1	1	1	3	1				2
Cont. plummerae	23	33	37	31	9	37	17	15	17	15	9		14
Cont. walfishensis													
Cont. sp.			1						1			1	
Gan. gansseri													2
G. wiedenmayeri				1									
Gl. multispina			1					1	3				
Gl. prairiehillensis	2									2			
Gl. rosebudensis	5	1			5	2	4	7	3	6		1	
Gl. subcarinatus	7	7	5		7		2	7	7	10	2	1	4
Gl. volutus	1	3	1	2	4		6	5	5	5	4	3	
Gl. yaucoensis	6	3	1	1	3	1	4	4	2	3	4	7	2
Gl. sp.													
Globotruncana aegyptiaca	10	14	26	22	15	15	12	20	20	13	24	5	17
Globotruncana arca	5	5	11	13	4	3	6	5	6	4	17	7	17
Gna. bulloides	23	21	13	15	13	13	9	13	18	16	18	6	37
Globotruncana falsostuarti	2	3	4	4	2	3			3		2		10
Globotruncana linneiana		8	5	11	3	3	6	2	2	4	5		5
Globotruncana mariei		2	5	5	2	6	3	3	2	2	4		3
Globotruncana orientalis	1			4	2	3					2		5
Globotruncana rosetta	5	1	3	2	1	5		3	1	1	1		2
Globotruncana ventricosa	4	2	2	3	3	5	3	2	2		3	3	3
Globotruncana sp.		2	1	3			2				2		
Globotruncanella havanensis	3	1	2		2			2					
Globotruncanella minuta	1		1										2
Globotruncanella petaloidea	1	2	2	3	5		2	1					
Globotruncanella pschadae													
Globotruncanella sp.				1									
Globotrunca. atlantica											1		1
Globotrunca. angulata	1		3			2		4	1	5	1		8
Globotrunca. conica													2
Globotrunca. falsocalcarata		1									2	3	
Globotrunca. insignis		1	4	1		1		3	1		1	2	

Table 3. (Continued).

Globotrunca. pettersi	2	1	1	3	2	3	1			2	1	4	3
Globotrunca. stuarti	3				1	2				2	1		2
Globotrunca. stuartiformis	2		3	3		3		5	2	1	3	4	9
Radotruncan. subspinosa											1		
Radotrunc. cf. *subspinosa*													
Globotruncanita sp.		1	12	2	2		1	1	6			1	
Gublerina acuta	2		1			1	2	2	4	1	1	2	
Gublerina cuvillieri	2	1										3	
Guembelitria cretacea					1		1						
Guembelitria trifolia	1		1									2	
Hed. flandrini	1												
Hed. holmdelensis	2	5	5	3	7	2	1	3	1	3	6	1	1
Hed. monmouthensis	1	3			1	1			2				
Hedbergella simplex	1									2			
Hedbergella sp.		3	1		1			1	1			1	
Het. dentata	3	1	2		1	1		1				2	2
Het. glabrans	9	2	2	1	1	2	1		1				4
Het. globulosa	22	16	12	9	14	10	29	18	41	20	18	58	26
Heterohelix sp. 1				1		2			1		5		
Heterohelix spp.	7	24	77	25	58	55	38	36	68	32	23	48	95
Het. labellosa	7	19	2	10	8	8	3	3	16	4	10	3	4
Het. navarroensis	41	42	40	20	35	26	32	22	53	40	41	49	52
Het. planata	8	8	5	2	11	2	14	3	18	7	12	1	20
Het. pulchra	3	1	4	1	2				1	1		4	1
Het. punctulata	13	7	12	9	7	6	4	5	9	8	6	7	26
Pl. acervulinoides										1	3		
Plano. carseyae											1		
Plano. manuelensis		2			1								
Plano. multicamerata		2			1					1			
Plano. riograndensis		1		1	1				1				2
Planoglobulina sp.													
Pseudog. costellifera	3	2	5	6	4	4	2	5	13	1	3	23	4
Pseudog. costulata	23	11	21	10	23	13	39	24	27	10	20	27	25
Pseudog. excolata	2	5	8	1	3	2	1	1		1		3	
Pseudog. kempensis	1	7	2		6	3	2	2	5	2	2	9	
Pseudog. palpebra		1	2	3		2	1	1	2	2	2	4	6
Pseudog. sp.	4	4			3								5
Pseudop. austinana					2								
Pseudotex. intermedia													
Pseudotex. nuttalli	3	14	16	7	8	18	8	21	5	17	4	6	22
Pseudotextularia sp.													
Pseudotex. elegans													
Rg. hexacamerata	10	9	2	8	5	2	15	6	7	12	13	4	8

Table 3. (Continued).

Rg. macrocephala	4	4		4	2	2			4	2	4		4
Rg. milamensis	1	2	1	1					5		1		3
Rg. pennyi	6	3		2	1	1	2	2					3
Rg. reicheli	3	1	1		1		6	1	1	1	5	3	
Rg. rotundata													
Rg. rugosa	13	5	6	6	11	2	12	7	11	16	15	1	10
Rg. rugo-hexacam.													
Rg. rugo-macroceph.												1	
Rg. scotti				1	2		2	1			2		3
Rg. sp.	1	5	3	2	12	8	11	9	35	26	24	23	1
Schack. multispinata					1								
Counted specimens*	339	376	413	303	330	312	321	304	445	339	348	355	539
Counted foraminifers for P/B ratio**	301	302	303	300	300	300	300	321	301	314	302	311	329
Counted planktonic specimens**	289	292	293	291	279	285	277	301	291	300	283	287	328

*Total of planktonic species specimens from sample splits.
**Counted planktonic and benthic specimens from each sample split differently from counted planktonic specimens.
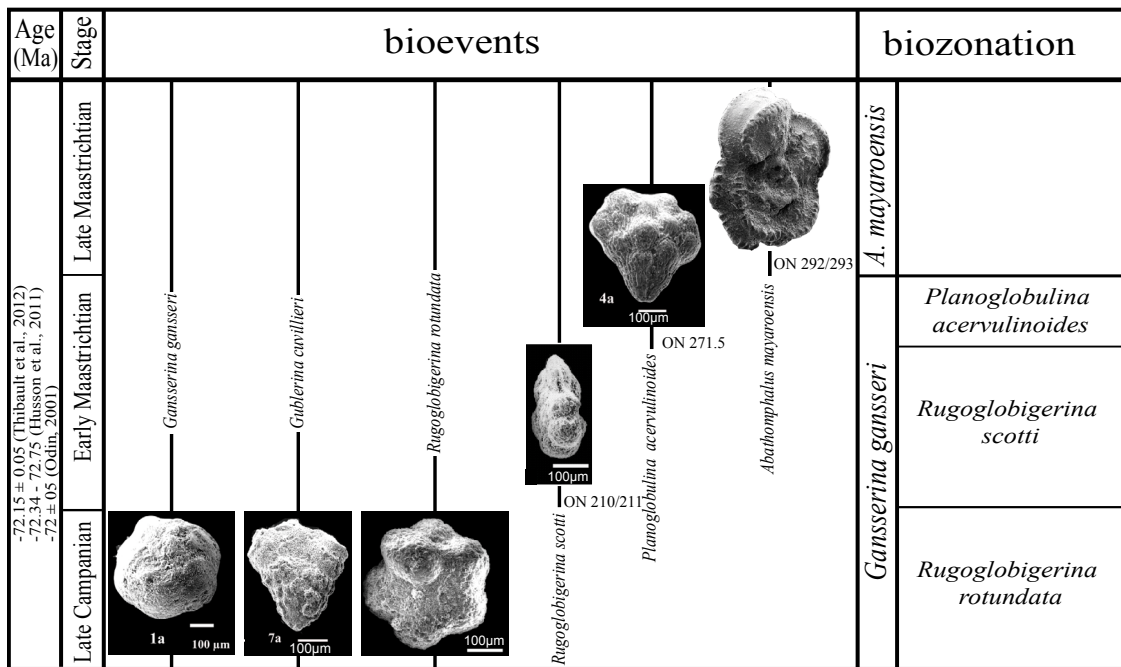
Figure 5. Proposed subzonation and relevant bioevents for the Campanian-Maastrichtian transition at the Oued Necham section.

occurrence of *Globotruncanella pschadae* (sample ON 212; Unit B, Figure 4) and *Abathomphalus intermedius* (sample ON 215; Unit B, Figures 4 and 6), associated with a remarkable change within the lineage of *Bolivinoides* species (benthic foraminifera). The upper part of the subzone is marked by the only occurrence of *Pseudotextularia intermedia*.

Because the C/M boundary ammonite marker species *Pachydiscus neubergicus*, documented to cooccur elsewhere with the LO of *Rugoglobigerina scotti*, is absent
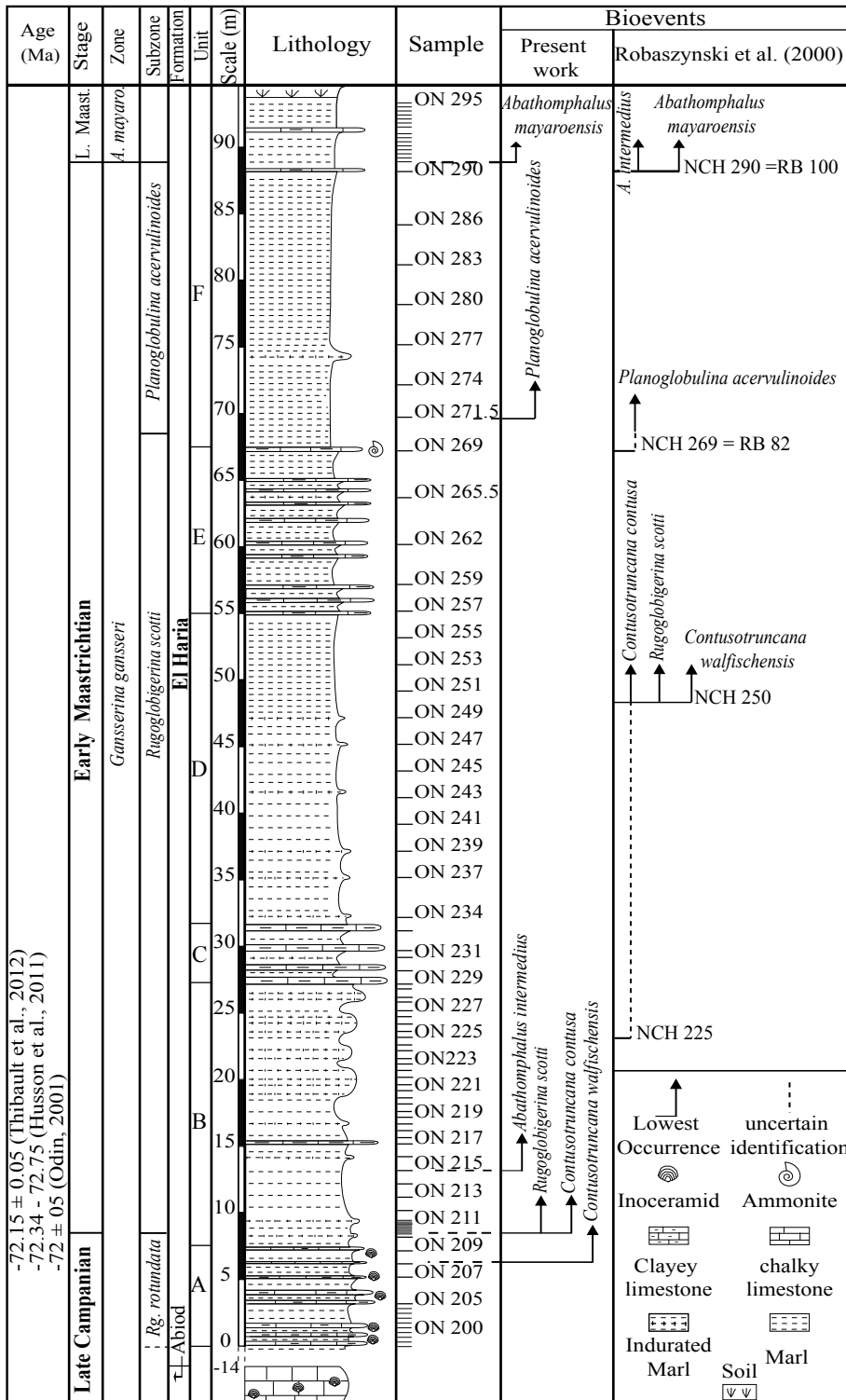
Figure 6. Comparison between observed bioevents in this work and those recognised by Robaszynski et al. (2000) at the Oued Necham section.

at the Oued Necham section, the planktonic foraminiferal assemblages within the *Rugoglobigerina scotti* Subzone are proposed as indicative of an early Maastrichtian age

with the consensus formally adopted during the Second International Symposium on Cretaceous Stage Boundaries, Brussels, 1995 (Figure 7).

Figure 7. Comparison of the proposed biozonation of this paper with a number of proposed biozonations for the Campanian-Maastrichtian transition.

Figure 7. (Continued).

4.1.3. *Planoglobulina acervulinoides* Subzone

Nederbragt (1991) initially used the taxon *Planoglobulina acervulinoides* to define a zone that spans the interval between the LO of *Planoglobulina acervulinoides* and the LO of *Racemiguembelina fructicosa*.

In the present work, the offset of this subzone is substituted and is defined by the LO of *Abathomphalus mayaroensis*, due to the absence of *Racemiguembelina fructicosa*. Perhaps the LO of *Racemiguembelina fructicosa* could not yet be reached in the studied section since Robaszynski et al. (2000) reported its occurrence a few meters above that of *Abathomphalus mayaroensis* southwestward, close to the "Table de Jugurtha" location.

Thus, the proposed *Planoglobulina acervulinoides* Subzone extends 20 m from sample ON 271.5 to ON 291, the interval of Unit F (Figures 4 and 6) that

encloses the LO of *Planoglobulina acervulinoides* and the LO of *Abathomphalus mayaroensis*. This subzone can be correlated with the upper part of the standard *Gansserina gansseri* Zone (Figure 7), indicative of the early/late Maastrichtian transition. In fact, it is the general consensus that the LO of *Abathomphalus mayaroensis* is documented to indicate the onset of the late Maastrichtian (e.g., Robaszynski et al., 1984; Arz, 1996; Arz and Molina, 2002).

It is worth nothing that heterohelicids within this subzone show a gradual diversification expressed by the emergence of complex multiserial and coarsely striate forms (e.g., *Racemiguembelina powelli*), heralding the onset of taxonomic high diversity within the lineage of heterohelicids, which is reported for the late Maastrichtian (Nederbragt, 1991; Li and Keller, 1998b).
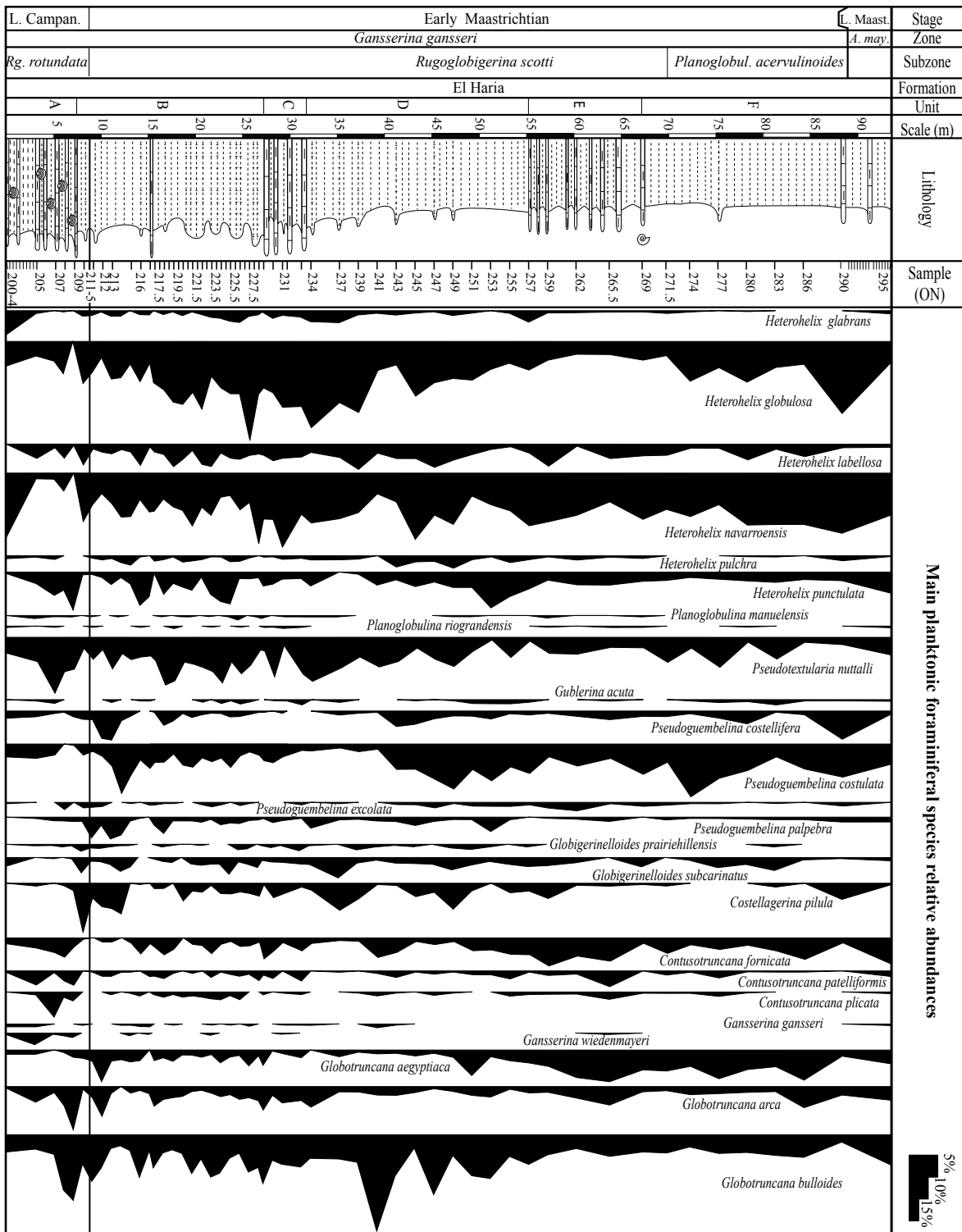
Figure 8. Relative abundances of planktonic foraminiferal species at the Oued Necham section throughout the Campanian-Maastrichtian transition.
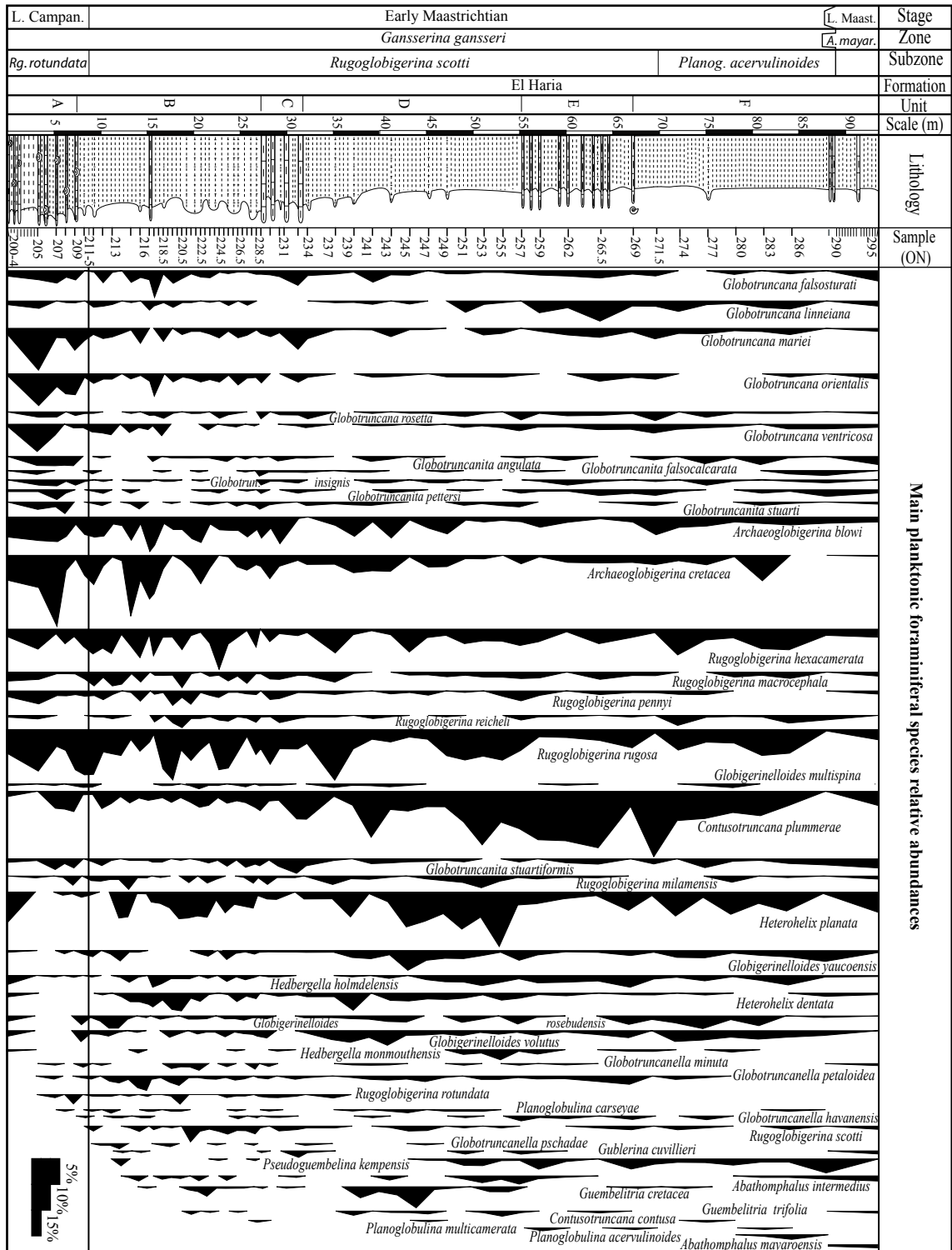
Figure 8. (Continued).
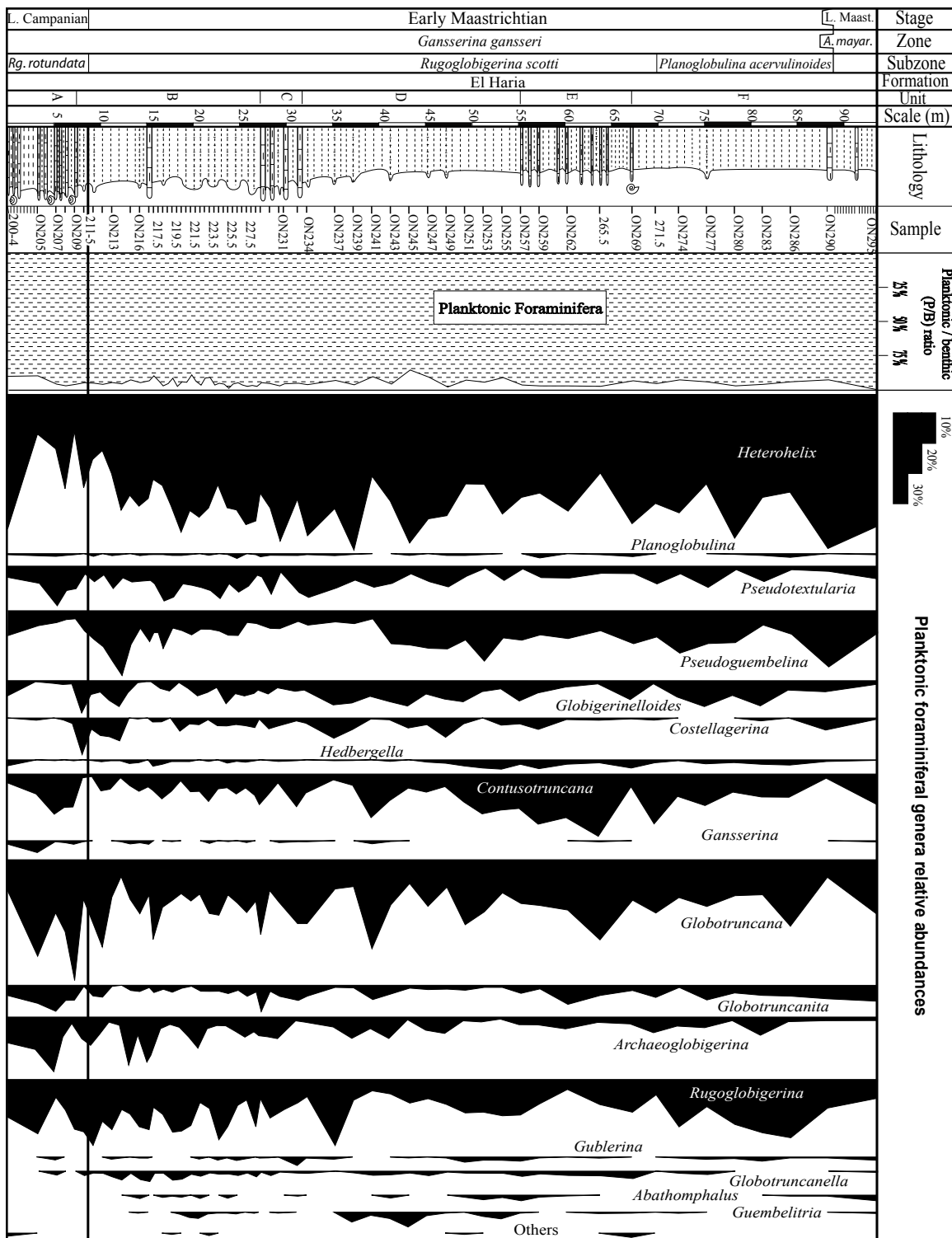
Figure 9. Planktonic/benthic ratio and planktonic foraminiferal genera relative abundances at the Oued Necham section throughout the Campanian-Maastrichtian transition.

4.2. Palaeoecology and depositional environment

Planktonic foraminifera are indeed very useful in biostratigraphy, and they can be used as a powerful proxy in the interpretation of depositional environments (Nederbragt, 1991; Arz, 1996; Li and Keller, 1998b; Hart, 1999; Arz and Molina, 2001; Petrizzo, 2002;
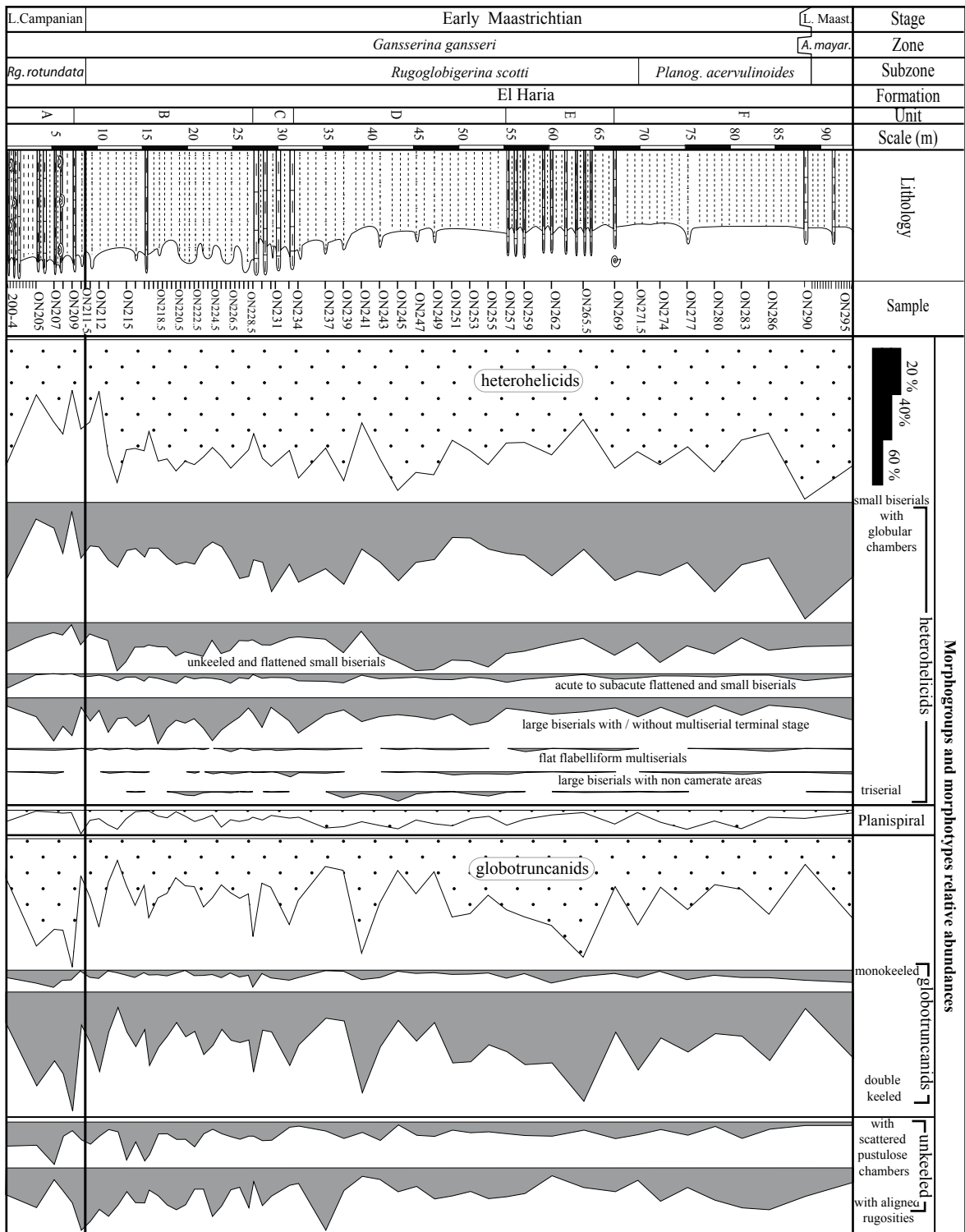
Figure 10. Morphotype frequencies at the Oued Necham section throughout the Campanian-Maastrichtian transition.

Abramovich et al., 2003; El-Sabbagh et al., 2004; El Amri and Zaghbib-Turki, 2005; Abramovich et al., 2010). Planktonic foraminifera are also suitable to highlight climatic changes by the geochemical record of their tests

(δ^{18}O and δ^{13}C stable isotopes) (Boersma and Shackleton, 1981; D'Hondt and Arthur, 1995; Barrera et al., 1997; Jarvis et al., 2002; Paul and Lamolda, 2007; Abramovich et al., 2010). In addition to isotopic data, a number of
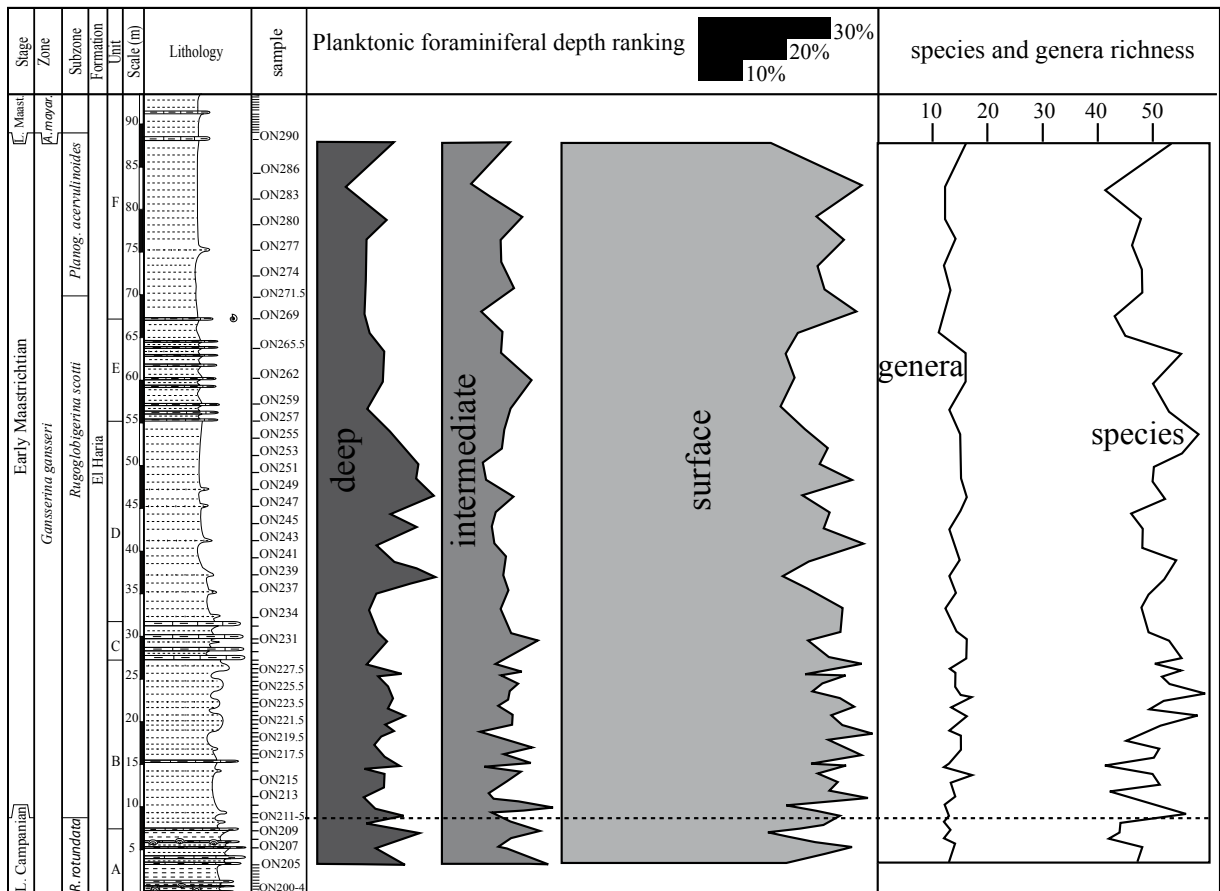
Figure 11. Water depth ranking of species niches (according to Arz, 1996; Li and Keller, 1998b; Arz and Molina, 2001) and species and genera diversity throughout the Oued Necham section.

other parameters such as test morphology together with relative abundances of morphogroups, known to be closely related to foraminiferal life history strategies (k and r) and water column partitioning, can also document climatic and abiotic changes induced to different niches within the same marine ecosystem (Hart, 1999; Petrizzo, 2002; El-Sabbagh et al., 2004; Abramovich et al., 2010). Climatic and/or abiotic changes can cause extinctions, faunal turnovers, and/or relative abundance fluctuations, which affect the most sensitive species, genera, and/or morphogroups, known as specialists in the literature. On the other hand, these changes can also favour the most tolerant morphotypes, known as opportunists.

Such a foraminiferal response has been expressed by their readjustment and iterative evolution through geological times (Coxall et al., 2007) as they endured repeated unsuitable ecological conditions of different degrees and natures as exemplified during the Santonian/ Campanian boundary (Petrizzo, 2002; El Amri and Zaghbib-Turki, 2014), the K/Pg boundary (Smit, 1982; Keller, 1988; Li and Keller, 1998b; Molina et al., 1998; Zaghbib-Turki et al., 2001; Molina et al., 2006, 2009).

These known parameters are used in an attempt to characterise the palaeoecological conditions of the sedimentary succession at Oued Necham by defining the composition of planktonic foraminiferal assemblages in terms of species, genera, and morphotypes and by studying their relative abundances (Figures 8–11) through the late Campanian to Maastrichtian interval. Thus, the P/B ratio and species and genera diversity were calculated and plotted in Figures 9–11. Moreover, 12 morphotypes were defined based on test morphology: 1) small biserials with globular chambers, 2) unkeeled and flattened small biserials, 3) acute to subacute flattened and small biserials, 4) large biserials with or without a multiserial terminal stage, 5) flat and flabelliform multiserials, 6) large biserials with noncamerate areas and 7) triserials among heterohelicids, 8) planispiral, and 9) monokeeled and 10) double-keeled among globotruncanids and unkeeled taxa presenting 11) scattered pustulose chambers and 12) meridionally aligned rugosities on their chambers among rugoglobigerinids (Figure 10). As shown in Figure 11, species were also grouped into surface, intermediate, and deep dwellers referring to Arz (1996) and Li and

Keller (1998b). Furthermore, the herein assumed r and k ecological strategies adapted by planktonic foraminifera mainly follow the works of Hart (1999) and Petrizzo (2002).

The results show that P/B ratio counts are quite stable throughout the section and range from 85% to 99% (Figure 9), suggesting an upper to middle bathyal depositional environment (Murray, 1897; Bertagoni et al., 1977; Damak-Derbel et al., 1991). The palaeobathymetry for the studied section concurs with the predominance of pelagic fauna (e.g., planktonic foraminifera, calcareous nannofossils) associated with common benthic foraminifera and ostracods (Robaszynski et al., 2000; this work).

Species extinction at any level of the studied series was not documented, although several species are scarce and sporadic (e.g., *Gublerina cuvillieri*, *Pseudotextularia intermedia* among heterohelicids, *Gansserina gansseri*, *Globotruncanita falsocalcarata*, *Gta. conica*, *Radotruncana subspinosa*, *Contusotruncana contusa* among keeled globotruncanids, and *Schackoina multispinata* among planomalinids).

The results further show that genera and species diversity distribution patterns display similar global trends throughout the studied section; however, the number of species shows distinct short-term high-amplitude cyclic fluctuations in the lower part of the section (Figure 11). Regarding morphogroups, globotruncanids (mostly double-keeled) and small heterohelicids dominate the planktonic foraminiferal assemblages in opposite phases. These dominant groups are associated with common rugoglobigerinids and other unkeeled taxa with globular chambers and smooth to irregular surface. The coiled planispiral *Globigerinelloides* species are poorly developed throughout the studied section and show a continuous and quite stable abundance slightly increasing through the Maastrichtian (~10%). Assemblages with the predominant species previously mentioned are also associated with scarce to periodically absent triserial, flat, and flaring multiserial heterohelicids (Figure 10).

During the latest Campanian (upper part of the *Rugoglobigerina rotundata* Subzone), assemblages are characterised by an average of 45 species belonging to 15 genera, which include 60% surface dwellers while intermediate and deep water dwellers share the same relative percentages (~20%, respectively). Morphotypes particularly distinctive of this time are represented by double-keeled globotruncanids that reached ~60% of the assemblages (Figure 10), mainly composed of *Globotruncana* (Figure 9). Double-keeled globotruncanids are also associated with common heterohelicids dominated by large and small biserials (e.g., *Pseudotextularia nuttalli*, *Heterohelix punctulata*, *Hx. globulosa*) and less frequent rugoglobigerinids. At the species level, assemblages are dominated by *Globotruncana bulloides* (most abundant

of the genus, reaching 15% of the assemblages), *Rugoglobigerina rugosa*, and *Heterohelix globulosa* (Figure 8).

Species diversity shows a gradual increase through the early Maastrichtian, with assemblages fluctuating rapidly then progressively within the lower and upper parts of the *Rugoglobigerina scotti* Subzone (Figure 11). Total counts range from 45 up to 60 species, whereas genus diversity varies from 15 to 20 (Figure 11). The values for genus diversity remain quite stable throughout the *Rugoglobigerina scotti* Subzone with only moderate fluctuation, but decline concurrently with species diversity at the onset of the *Planoglobulina acervulinoides* Subzone, reaching the lowest counts of 11 genera and 45 species.

Overall assemblages are dominated by small biserial heterohelicids throughout the early Maastrichtian, reaching ~50% (Figure 10) in association with other morphotypes such as double-keeled globotruncanids (~30%) and rugoglobigerinids (~20%). As shown in Figure 10, the relative abundance of double-keeled globotruncanids decreases in the earliest Maastrichtian and then shows brief episodes of increase towards the *Abathomphalus mayaroensis* Zone, without exceeding late Campanian values. Rugoglobigerinids show moderate relative abundances in general (10%–30%), but undergo an obvious decrease throughout the interval between samples ON 239 and ON 265.5. *Rugoglobigerina rugosa* remains the dominant species, reaching alone ~10% of the assemblages. The relative abundance of heterohelicids increased progressively within the lower part of the *Rugoglobigerina scotti* Subzone and reaches up to 70%. It decreases progressively towards the *Planoglobulina acervulinoides* Subzone (close to 50% in relative abundances), coinciding with increases in frequencies of keeled taxa (e.g., *Globotruncana* spp.).

Whereas globotruncanids frequencies decrease (close to 30%) through the *Planoglobulina acervulinoides* Subzone, heterohelicid relative abundance remains quite stable (50%) and then increases progressively towards the *Abathomphalus mayaroensis* Zone, reaching up to 70% of the assemblages. Apart from the least abundant flat and flaring multiserial forms within the *Planoglobulina acervulinoides* Subzone, heterohelicids also show distinct thriving multiserial forms within the *Pseudotextularia-Racemiguembelina* lineage, dominated by *Pst. nuttalli* (~13% in relative abundance). However, *Racemiguembelina* species are very scarce; thus, only a few *Pst. intermedia* and very rare *R. powelli* are reported while *R. fructicosa* is totally absent. Globally, the *Racemiguembelina fructicosa* LO is documented to coincide or not with that of *Abathomphalus mayaroensis* (Figure 7). The published record indicates that the *Racemiguembelina fructicosa* LO
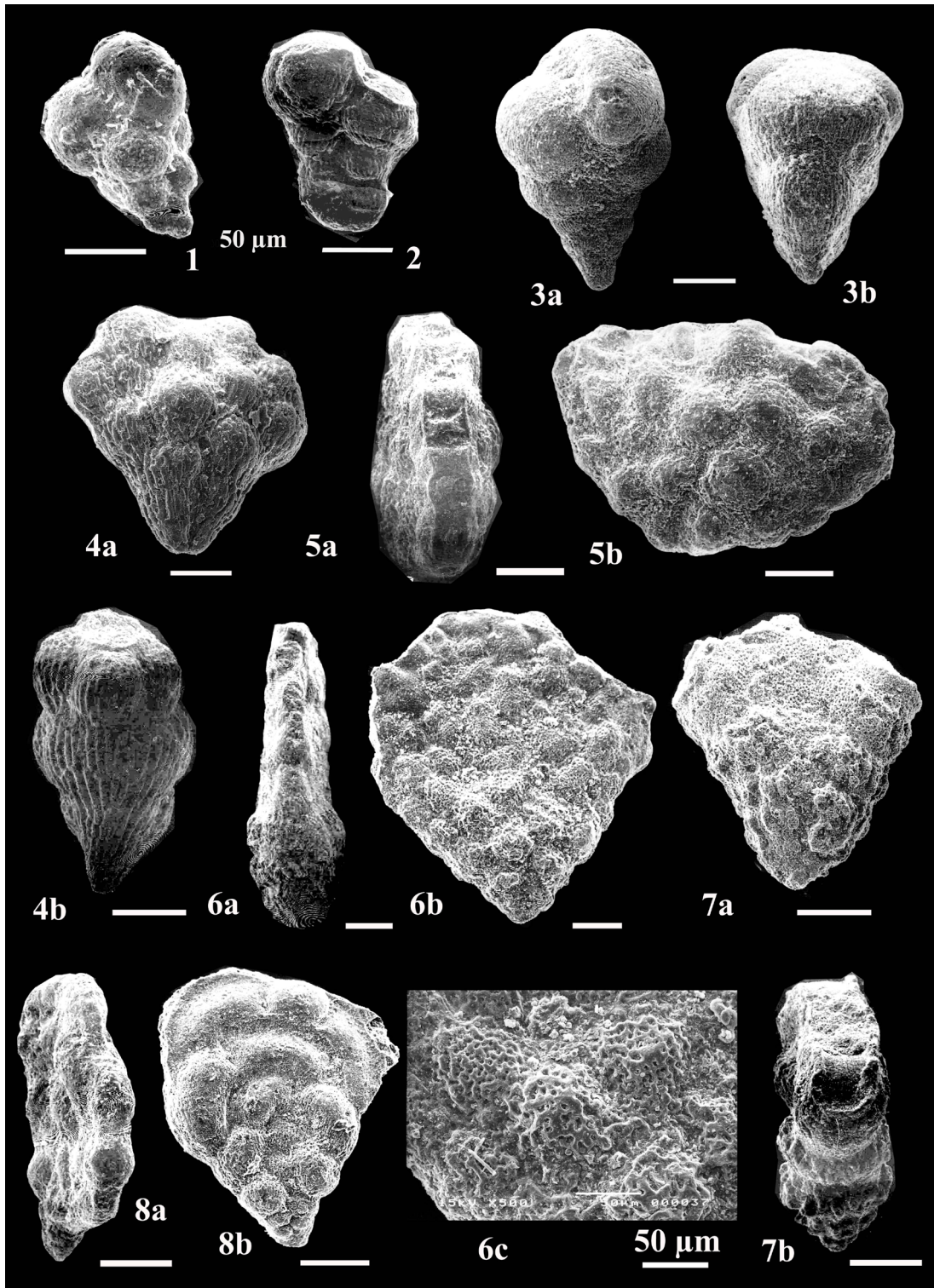
Figure 12. 1. *Guembelitria cretacea* Cushman, 1933; sample ON 239. 2. *Heterohelix navarroensis* Loeblich, 1951; sample ON 290. 3a and 3b. *Pseudotextularia nuttalli* (Voorwijk, 1937); sample ON 208. 4a and 4b. *Planoglobulina acervulinoides* (Egger, 1899); sample ON 271.5. 5a and 5b. *Planoglobulina manuelensis* (Martin, 1972); sample ON 212. 6a–6c. *Planoglobulina multicamerata* (de Klasz, 1953); sample ON 262. 7a and 7b. *Gublerina cuvillieri* Kikoine, 1948; sample ON 262. 8a and 8b. *Gublerina acuta* de Klasz, 1953b; sample ON 208. Scale bar represents 100 µm (except for 1, 2, and 6c).
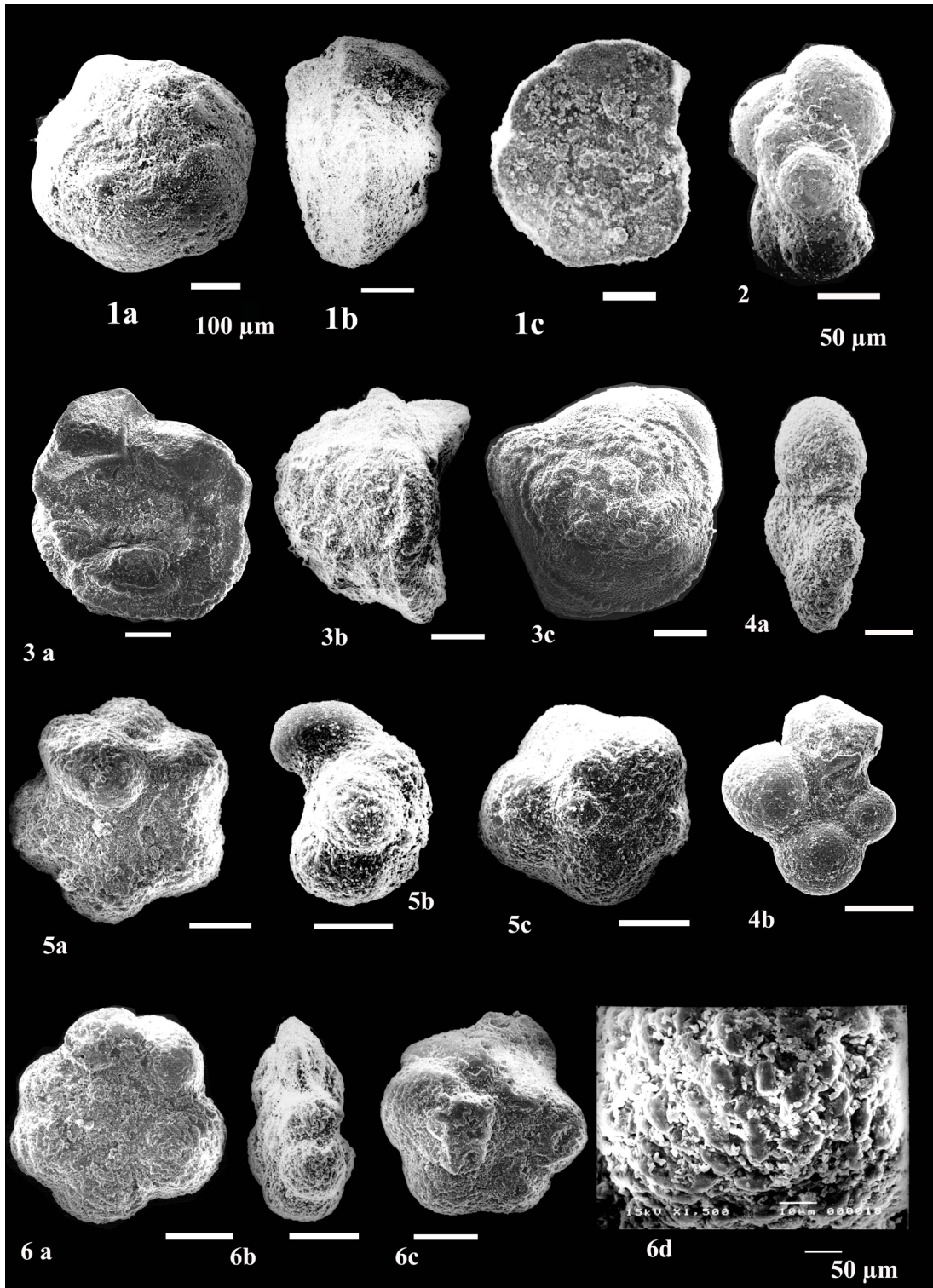
Figure 13. 1a–1c. *Gansserina gansseri* (Bolli, 1951); sample ON 205. 2. *Hedbergella monmouthensis* (Olsson, 1960); sample ON 208. 3a–3c. *Contusotruncana contusa* (Cushman, 1926); sample ON 249. 4a and 4b. *Globigerinelloides subcarinatus* (Brönnimann, 1952); sample ON 213. 5a–5c. *Rugoglobigerina rotundata* Brönnimann, 1952; sample ON 211. 6a–6d. *Rugoglobigerina scotti* (Brönnimann, 1952); sample ON 211. Scale bar represents 100 µm (except for 2 and 6d).

may occur earlier (Caron, 1985; Nederbragt, 1991; Arz, 1996; Arz and Molina, 2002; Ogg and Ogg, 2004; Huber et al., 2008), simultaneously (Gasinski and Uchman, 2009) or subsequently (Robaszynski et al., 2000) to the LO of *Abathomphalus mayaroensis*. The absence of this species in the studied section suggests that the Kalâat Senan area was probably locally influenced by special environmental conditions that may have affected the *Racemiguembelina* lineage distribution.

4.3. Discussion and interpretation

4.3.1. Biostratigraphic correlation

Referring to the Second International Symposium on Cretaceous Stage Boundaries, Brussels, 1995, the long-time use of the *Radotruncana calcarata* HO to specify the C/M boundary (Herm, 1962; Bolli, 1966; Postuma, 1971; Van Hinte, 1976; Sigal, 1977; Saïd, 1978; Salaj, 1980; Bellier, 1983; Robaszynski et al., 1984; Caron, 1985; Mancini et al., 1996; Rami et al., 1997; Li and Keller, 1998b; Li et al., 1999) is no longer valid (Figure 7). Accordingly, henceforth the *Radotruncana calcarata* HO corresponds to the mid-Campanian, as it occurs much earlier than the LO of *Pachydiscus neubergicus* (Odin, 2001, 2002; Ogg and Ogg, 2004). Indeed, newly identified bioevents document a younger absolute age for the C/M boundary (Odin, 2001, 2002; Ogg and Ogg, 2004; Gardin et al., 2012; Thibault et al., 2012; Batenburg et al., 2014; Thibault et al., 2015).

The results of the high-resolution study in Kalâat Senan revealed a number of discrepancies (Figure 6) between species occurrences recognised in this work and those plotted by Robaszynski et al. (2000). Apart from sampling resolution, which could have affected the accuracy of temporal distribution of certain species (e.g., *Rugoglobigerina scotti*, *Contusotruncana contusa*, *C. walfishensis*), results suggest that modulating ecologic and climatic factors (discussed below) may have also been involved, resulting in their temporary absences (Figure 4) and the reported discrepancies. Moreover, the LO of the subzonal biomarker *Rugoglobigerina scotti* used in this work was not considered by Robaszynski et al. (2000) as an early Maastrichtian indicator. However, the authors placed the C/M boundary within their *Archaeoglobitruncana kefiana*? Subzone using the HO of *Nostoceras* (*Nostoceras*) *hyatti*. The latter was reported within the interval of samples NCH 72 and NCH 75, which is much lower than sample NCH 165 where they indicated the presence of an inner mould of *Pachydiscus neubergicus*, an index species marker of the C/M boundary. Accordingly, if we consider the reported *P. neubergicus* mould as a reliable occurrence, it seems logical that moving up the boundary position at least to the level of sample NCH 165 should be a viable alternative (~50 m lower than the present work's proposal).

Compared to the Tercis-les-Bains GSSP of the C/M boundary, in south-western France (Arz and Molina,

2001, 2002), the biostratigraphic record of Maastrichtian planktonic foraminifera at the studied section seems to be more complete, because of the presence of key index species frequently used in biostratigraphy (Figure 7), such as *Gublerina cuvillieri* (Figure 12), *Gansserina gansseri* (Figure 13), and *Abathomphalus mayaroensis*, not found at the GSSP section. According to Arz and Molina (2001, 2002), the *P. acervulinoides* Subzone was not recognised at the Tercis-les-Bains section due to "inadequate outcrop". Consequently, the "inadequate outcrop" prevented identification of the upper limit of the *Rugoglobigerina scotti* Subzone, as well. Nonetheless, both foraminiferal *Rugoglobigerina scotti* and *Contusotruncana contusa* (Figure 13) LOs are coincident at the Tercis-les-Bains GSSP section, as is the case at the Oued Necham section (Robaszynski et al., 2000; this work). However, while the *Rugoglobigerina scotti* LO is considered a widespread synchronous bioevent (Robaszynski et al., 1984; Arz and Molina, 2001), the LO of *Contusotruncana contusa* is known to be diachronous. In fact, the LO of *Contusotruncana contusa* can be recorded in different chronologic orders as follows: 1) prior to that of *Rugoglobigerina scotti*, like at the Alamidella section in Spain (Arz, 1996) and the Blake Nose core in the North Atlantic (Huber et al., 2008); 2) coincident with the LO of *Rugoglobigerina scotti*, like at the Musquiz section in Spain (Arz, 1996), Tercis section in France (Arz and Molina, 2001; Odin, 2001, 2002; Odin et al., 2001; Arz and Molina, 2002), Oued Necham in central Tunisia (Robaszynski et al., 2000; this work), and western central Sinai in Egypt (El-Sabbagh et al., 2004); and 3) subsequent to the LO of *Rugoglobigerina scotti*, like at the Zumaya section in Spain (Arz, 1996; Arz and Molina, 2002).

Taking into account the reported coincidence between *Rugoglobigerina scotti* and *Pachydiscus neubergicus* LOs (Arz, 1996; Odin, 2001; Arz and Molina, 2001, 2002) on one hand, and on the other the diachronism of the *Contusotruncana contusa* LO, we consider the LO of *Rugoglobigerina scotti* to be an excellent foraminiferal bioevent indicative of the early Maastrichtian (Figure 7), especially in the absence of the ammonite index species of the stage boundary. In addition, the newly identified boundary position at the Oued Necham section can also be approximated, in accordance with Arz (1996), Arz and Molina (2001) and El Sabbagh et al. (2004), based on a number of other species documented to occur closely to *Rg. scotti* (e.g., *Gublerina cuvillieri*).

Based on the high-resolution biostratigraphic results at the Oued Necham section, the C/M boundary may no longer be placed within the intermediate member (using the *Radotruncana calcarata* HO) of the Abiod Formation (equivalent to the Akhdar member) in Tunisian outcrops (Figure 3), but rather just above the inoceramid-rich limestone beds of the transitional Abiod-El Haria Gouss
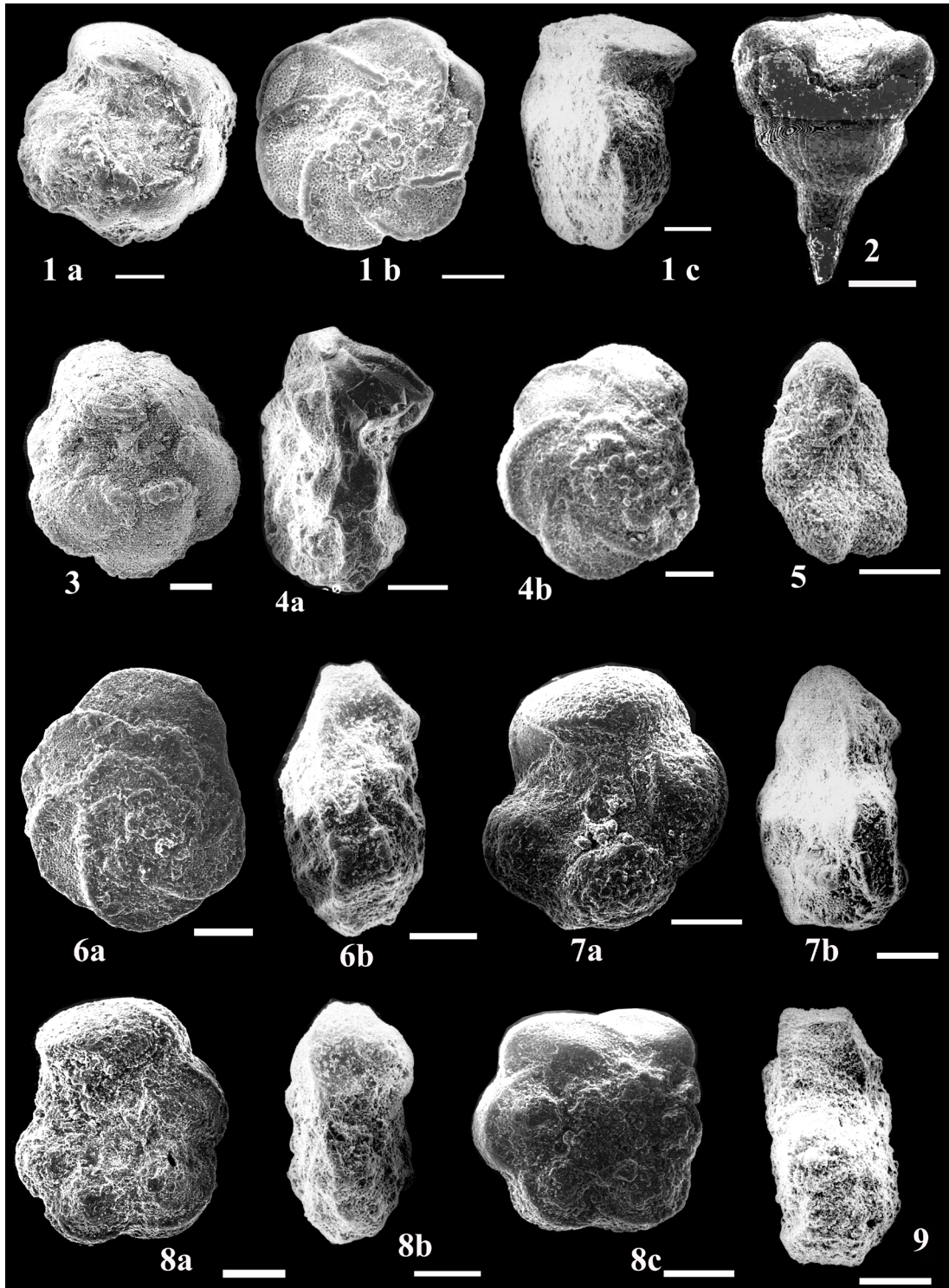
Figure 14. 1a–1c. *Globotruncanita angulata* (Tilev, 1951), a and b. Sample ON 218, c. sample ON 214. 2. *Pseudotextularia intermedia* De Klasz 1953; sample ON 283. 3. *Globotruncanita insignis* (Gandolfi, 1955); sample ON 217.5. 4a and 4b. *Globotruncana ventricosa* White 1928; sample ON 211. 5. *Globotruncanella havanensis* (Voorwijk, 1937); sample ON 212. 6a and 6b. *Globotruncana arca* (Cushman, 1926), a. sample ON 212, b. sample ON 211. 7a and 7b. *Globotruncana aegyptiaca* (Nakkady, 1950), a. sample ON 205, b. sample ON 271.5. 8a–8c. *Globotruncana bulloides* (Vogler, 1941); sample ON 208. 9. *Globotruncana linneiana* (d'Orbigny, 1839); sample ON 262. Scale bar represents 100 μm.

member. This implies that the uppermost part of the Abiod and the basal part of the El Haria Formations, previously considered Maastrichtian, should be assigned to the Campanian.

4.3.2. Palaeoecologic interpretation

The gradual increase affecting *Heterohelix*, *Pseudoguembelina*, *Globigerinelloides*, *Costellagerina*, and *Rugoglobigerina* species during the early Maastrichtian was also reported at other localities by Arz (1996), Arz and Molina (2001), and especially Li and Keller (1998b) in El Kef and Elles, north-western Tunisia. These small-sized taxa are almost unornamented, have been interpreted to inhabit cold surface/subsurface open sea waters (Arz, 1996; Hart, 1999; Arz and Molina, 2001; Petrizzo, 2002), and suggest an "r" ecological strategy (Hart, 1999; Petrizzo, 2002), except for *Globigerinelloides* species that are reported to fluctuate between shallow and cold deeper subsurface waters (Abramovich et al., 2003). The relative abundance of *Globigerinelloides* species (~10%) in the Oued Necham section is similar to that reported in the Negev (Abramovich et al., 2010). Nonetheless, the association of commonly abundant double-keeled taxa at the Oued Necham section suggests oligo- to mesotrophic conditions.

Indeed, the foraminiferal assemblages and temporal variations observed in the studied section rather support steady mesotrophic conditions (Petrizzo, 2002), because increased heterohelicid, planispiral, and rugoglobigerinid morphotypes coincide with a distinct decrease in globotruncanids (Figure 14), which are assumed to be specialists and mostly deep dwellers (except for *Contusotruncana*, considered after Arz (1996) as surface dwellers). Such a temporal pattern of these foraminiferal assemblages that varied in opposite phases may have been related to near surface and subsurface water temperature decrease in the early Maastrichtian (Boersma and Shackleton, 1981). This drop in temperature is considered as the least recorded temperature during the late Cretaceous (Jones and Simmons, 1999; Boersma and Shackleton, 1981; Barrera, 1994; Barrera et al., 1997; Abramovich et al., 2003; Batenburg et al., 2014) that probably spread to the Tethyan realm. Petrizzo (2002) also considered a "long-term cooling trend" to have settled in the Tethyan realm from the late Turonian to the Maastrichtian with intermittent short warming episodes.

Assemblages of k-strategist or specialist taxa with abundant double-keeled taxa (Figure 14) in the late Campanian, which subsequently became intermittent during short intervals in the Maastrichtian, are considered to inhabit the warm subsurface mixed layer. Hence, in Kalâat Senan these taxa are thought to indicate well-established suitable ecological conditions within warm and oligotrophic open ocean waters (Li and Keller,

1998b; Petrizzo, 2002; Abramovich et al., 2003, 2010). Among these taxa, the single-keeled morphotypes have been interpreted to inhabit the deepest part of the water column (Hart, 1999; Petrizzo, 2002) under meso- to oligotrophic conditions. These morphotypes are poorly represented in the Oued Necham section where they account for up to 10% of all the assemblages, and up to 5% at the species level. This record is interpreted to probably reflect a "readjustment to a slightly shallow habitat" (Petrizzo, 2002), or a response to changing conditions by developing a second keel due to a disruption related to the progressive cooling of water depth temperatures through time. The low abundance of heterohelicids concurrent with the fluctuations observed suggests either the effects of the "restricted oxygen minimum zone" reported by Li and Keller (1998b) in El Kef and Elles, in north-western Tunisia, or the result of the reported intermittent warming pulses within the progressive late Cretaceous ocean cooling trend (Boersma and Shackleton, 1981; Petrizzo, 2002). During the short-term warming episodes assumed to have occurred through the upper part of the *Rugoglobigerina scotti* Subzone and the *Planoglobulina acervulinoides* Subzone, heterohelicids are dominated by small biserials (Figure 10), especially by *Pseudoguembelina* species that reached more than 20% of the assemblages (Figure 9). Since *Pseudoguembelina* species are reported to indicate warmest temperatures (Boersma and Shackleton, 1981) and in the Oued Necham section their abundance is the opposite of the specialist taxa, they suggest a "more r- to r/k intermediate" ecological strategy.

Except *Guembelitria* species, which are documented to be warm opportunist taxa (Keller, 2002), the morphotypes that are poorly represented at the Oued Necham section are considered as "more r-selected r/k intermediate" ecological strategists displaying quite stable frequency ranges (Petrizzo, 2002): for instance, the poorly represented flat and flaring multiserial morphotypes (Figure 10), which are known to support cold water (Boersma and Shackleton, 1981).

Morphologic analyses of the multiserial heterohelicids in the Oued Necham section show an evolutionary tendency within the *Planoglobulina acervulinoides* Subzone, although *Racemiguembelina* species show scarce and discontinuous occurrences. Phylogenetic links could exist between *Pst. intermedia* and *R. fructicosa*, but a "complete range of morphotypes" has not been found at any single locality (Nederbragt, 1991, p. 366). However, our study of the Oued Necham section and DSDP site 357 (Nederbragt, 1991) revealed the occurrence of common *Pst. intermedia*, rare *R. powelli*, and intermediate specimens, but *R. fructicosa* is essentially absent. These findings allow us to concur with the assumption that *Racemiguembelina* species are "part of a cline" and their

distribution is closely related to special palaeoecological and palaeoenvironmental conditions (Nederbragt, 1991, p. 366). Similarly, Abramovich et al. (2003) suggested that an ancestral link could exist between *Pst. elegans* and *Racemiguembelina* spp. Hence, the absence of *R. fructicosa* close to the early/late Maastrichtian boundary (indicated by the LO of *Abathomphalus mayaroensis*) at the studied Oued Ncham section could also be related to the near absence of its potential ancestor *Pst. elegans*.

Concerning water depth and ecological niches partitioning, the increase in the frequencies of surface dwellers (more than 70% of the assemblages) globally parallels the increase in the number of species in the early Maastrichtian. This trend seems to be closely related to the documented cooling event, which favoured the proliferation of colder water taxa. High-frequency cyclic fluctuations of surface, intermediate, and deep dwellers denote the high climatic variability during the late Campanian-early Maastrichtian that seems to affect all the planktonic foraminiferal assemblages at all levels through the water column. Surface and deep dwellers experienced a sharp decrease through the upper part of the *Rugoglobigerina scotti* Subzone (samples ON 245 and ON 271.5 interval) while intermediate dwellers increased in frequencies. This opposite phase in the fluctuating pattern (surface and deep dwellers decrease vs. intermediate dwellers increase) corresponds to a sharp decline in species diversity and a slight drop in the number of genera (Figure 11). This pattern implies a well-stratified water column and better ecological conditions close to the thermocline boundary, which benefited most specialists and warm taxa (k-strategists increase) against opportunist and cold taxa (r-strategists decrease). Such a distribution is compatible with rises in sea water temperatures that probably happened for brief periods towards the early/late Maastrichtian (Boersma and Shackleton, 1981). Consequently, surface and deep dwellers probably suffered from temperatures rises and reduced dissolved oxygen within the "restricted oxygen minimum zone" (Li and Keller, 1998b). Through the *Planoglobulina acervulinoides* Subzone, surface dwellers increased against a constant to slightly decreasing intermediate and deep dwellers. This increase coincides with a remarkable trend that shows a decline in the number of species and genera reflecting an optimal surface water habitat probably marked by increasing upwelling and nutrient supply under eutrophic conditions (Li and Keller, 1998b). Such conditions would favour rapid reproduction of small-sized and simply ornamented taxa (Hart, 1999). The inverse pattern of a deep dwellers decrease (~10%) could be related to the "slight warming of deep water temperatures" (Boersma and Shackleton, 1981).

Compared to the GSSP of the C/M boundary (i.e. the Tercis-les-Bains section), and according to Arz and Molina

(2001), the P/B ratio is higher at the Oued Necham section, thus suggesting a deeper depositional environment (85%–99% at the studied section, i.e. upper-middle bathyal, this work, vs. <50% at the Tercis section, i.e. middle-outer shelf). Moreover, planktonic foraminiferal assemblages are more diversified at the Oued Necham section as many species are absent at the C/M boundary GSSP (e.g., *Guembelitria cretacea*, *Planoglobulina carseyae*, *Gublerina acuta*, *Pseudoguembelina excolata*, *Psg. palpebra*), perhaps due to the high palaeolatitudinal position and the shallow marine depositional environment of the Tercis GSSP (Arz and Molina, 2001, 2002). An additional constraint associated with the GSSP Tercis section is due to lithification, as it consists mostly of limestones that limit easy microfossil extraction and thereby accurate taxonomic identification.

Considering the newly defined C/M boundary age of –72, 15 ± 0.5 Ma (after Husson et al., 2011; Gardin et al., 2012; Thibault et al., 2012; Cohen et al., 2013; Batenburg et al., 2014; Husson et al., 2014; Thibault et al., 2015), the boundary seems to be located within the "Cam9" sequence, corresponding to a regressive cycle, bounded by a major (–73.14 Ma) and a minor (–70.78 Ma) relative sea level change (Snedden and Chengjie, 2010). This could probably be related to poleward development of ice caps during the late Cretaceous cooling event, especially through the early Maastrichtian (Barrera, 1994; Li and Keller, 1998a, 1998b).

5. Conclusion

In the present study of the Oued Necham section, the C/M boundary is newly defined on the basis of planktonic foraminifera in accord with the biostratigraphical recommendations during the Second International Symposium on Cretaceous Stage Boundaries, Brussels, 1995. Therefore, the defined boundary is marked by *Rugoglobigerina scotti* and *Contusotruncana contusa* LOs together with a coincident evolutionary tendency within the *Bolivinoides* lineage (benthic foraminifera).

The LOs of *Rugoglobigerina scotti* and *Contusotruncana contusa* are observed in the middle part of the *Gansserina gansseri* Zone, which is included stratigraphically within the lower part of the El Haria Formation. This implies that the boundary should henceforth be placed in the lowermost part of the El Haria Formation and that the underlying Abiod Fm. and the transitional Gouss member are Campanian in age.

Quantitative data of planktonic foraminifera provide further evidence of a significant climate cooling during the early Maastrichtian with intermittent short-term warming episodes in an open marine depositional environment. Although the lowest temperatures were recorded during the Maastrichtian, the results revealed no extinction within the planktonic foraminiferal assemblages. The specialist taxa (k strategists) showed a high diversity, mostly reaching their maximum numbers of species. The results imply

that extant conditions of high climate variability were not strong enough to cause extinction of specialist taxa, or one may assume that since the late Santonian turnover globotruncanids had acquired a sophisticated ecological strategy against water cooling, or that abiotic conditions improved since then.

Finally, excellent outcrops of a continuous Campanian-Maastrichtian series together with its richness and excellent preservation of pelagic fauna, notably planktonic foraminifera, provide unique distinctions for the Oued Necham section (Kalâat Senan, central Tunisia), which offers: 1) a coherent and complete foraminiferal biostratigraphical record through the upper part of the *Gansserina gansseri* Zone that may improve the C/M boundary definition at the GSSP, 2) a partly indurated clayey lithology that allows easy recovery of free foraminifera specimens suitable to achieve robust biostratigraphic and semiquantitative data, and 3) a low-mid latitudinal position in an open marine depositional environment (upper-middle bathyal) that is propitious to the occurrence of competitive opportunist and specialist taxa.

In conclusion, we hope that the new high-resolution biostratigraphic and semiquantitative data presented in the present work will shed further light to clarify the biochronology of the planktonic foraminiferal taxa that can be used as reliable indicators to define the C/M boundary in the Tethyan realm. The results will also unravel the palaeoecological conditions that prevailed during the C/M transition in Kalâat Senan.

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Appendix. Taxonomic list of cited planktonic foraminifera with author attributions and dates mentioned in the text and noted in Tables 1–3 and Figures 4, 5, 6, 7, 8, 12, 13, and 14.

Abathomphalus intermedius (Bolli, 1951)
Abathomphalus mayaroensis (Bolli, 1951)
Archaeoglobigerina blowi Pessagno 1967
Archaeoglobigerina cretacea (d'Orbigny, 1840)
Contusotruncana contusa (Cushman, 1926)
Contusotruncana fornicata (Plummer, 1931)
Contusotruncana patelliformis (Gandolfi, 1955)
Contusotruncana plicata (White, 1928)
Contusotruncana plummerae (Gandolfi, 1955)
Contusotruncana walfischensis (Todd, 1970)
Costellagerina pilula (Belford, 1960)
Gansserina gansseri (Bolli, 1951)
Gansserina wiedenmayeri (Gandolfi, 1955)
Globigerinelloides multispina (Lalicker, 1948)
Globigerinelloides prairiehillensis Pessagno, 1967
Globigerinelloides rosebudensis (Smith and Pessagno, 1973)
Globigerinelloides subcarinatus (Brönnimann, 1952)
Globigerinelloides volutus (White, 1928)
Globigerinelloides yaucoensis (Pessagno, 1960)
Globotruncana aegyptiaca (Nakkady, 1950)
Globotruncana arca (Cushman, 1926)
Globotruncana bulloides (Vogler, 1941)
Globotruncana falsostuarti (Sigal, 1952)
Globotruncana linneiana (d'Orbigny, 1839)
Globotruncana mariei (Banner and Blow, 1960)
Globotruncana orientalis (El Naggar, 1966)
Globotruncana rosetta (Carsey, 1926)
Globotruncana ventricosa White 1928
Globotruncanella havanensis (Voorwijk, 1937)
Globotruncanella minuta Caron & Gonzalez Donoso, 1984
Globotruncanella petaloidea (Gandolfi, 1955)
Globotruncanella pschadae (Keller, 1946)
Globotruncanita angulata (Tilev, 1951)
Globotruncanita atlantica (Caron, 1972)
Globotruncanita conica (White, 1928)
Globotruncanita falsocalcarata (Kerdany & Abdelsalam, 1969)
Globotruncanita insignis (Gandolfi, 1955)
Globotruncanita pettersi (Gandolfi, 1955)
Globotruncanita stuarti (de Lapparent, 1918)
Globotruncanita stuartiformis (Dalbiez, 1955)

Radotruncana subspinosa (Pessagno, 1960)
Gublerina acuta de Klasz, 1953b
Gublerina cuvillieri Kikoine, 1948
Guembelitria cretacea Cushman, 1933
Guembelitria trifolia (Morozova, 1961)
Hedbergella flandrini Porthault, 1970
Hedbergella holmdelensis Olsson, 1964
Hedbergella monmouthensis (Olsson, 1960)
Heterohelix dentata Stenestad, 1968
Heterohelix glabrans (Cushman, 1938)
Heterohelix globulosa (Ehrenberg, 1840)
Heterohelix labellosa Nederbragt, 1991
Heterohelix navarroensis Loeblich, 1951
Heterohelix planata (Cushman, 1938)
Heterohelix pulchra (Brotzen, 1936)
Heterohelix punctulata (Cushman, 1938)
Planoglobulina acervulinoides (Egger, 1899)
Planoglobulina carseyae (Plummer, 1931)
Planoglobulina manuelensis (Martin, 1972)
Planoglobulina multicamerata (de Klasz, 1953)
Planoglobulina riograndensis (Martin, 1972)
Pseudoguembelina costellifera (Masters, 1976)
Pseudoguembelina costulata (Cushman, 1938)
Pseudoguembelina excolata (Cushman, 1926)
Pseudoguembelina kempensis (Esker, 1968)
Pseudoguembelina palpebra Brönniman & Brown, 1953
Pseudoplanoglobulina austinana (Cushman, 1938)
Pseudotextularia intermedia de Klasz, 1953
Pseudotextularia nuttalli (Voorwijk, 1937)
Racemiguembelina powelli Smith & Pessagno, 1973
Rugoglobigerina hexacamerata Brönnimann, 1952
Rugoglobigerina macrocephala Brönnimann, 1952
Rugoglobigerina milamensis Smith & Pessagno, 1973
Rugoglobigerina pennyi Brönnimann, 1952
Rugoglobigerina reicheli Brönnimann, 1952
Rugoglobigerina rotundata Brönnimann, 1952
Rugoglobigerina rugosa (Plummer, 1926)
Rugoglobigerina scotti (Brönnimann, 1952)
Schackoina multispinata (Cushman & Wickenden, 1930)