Journal of Sciences, Islamic Republic of Iran 20(3): 233-242 (2009) http://jsciences.ut.ac.ir
University of Tehran, ISSN 1016-1104

Planktonic Foraminifera Response to Sudden Global Warming in Late Maastrichtian, a Case Study from Ziyarat-Kola, Central Alborz, Iran

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Received: 16 July 2008 / Revised: 21 October 2008/ Accepted: 23 November 2008

Abstract

An abrupt global warming event has been recorded in many parts of the world in sediments of Latest Maastrichtian age between 65.45-65.10 Ma. This warm event was documented here at a section near Ziyarat-kola in Central Alborz based on analysis of planktonic foraminifera. An unusual abundance of normally large-size species such as *Globotruncana arca, Globigerinelloides subcarinatus*, *Pseudoguembelina hariaensis* and *Rugoglobigerina rugosa* in small-size fraction (63-150) was recorded. A similar trend of increasing in relative abundance of some opportunist species such as *Guembelitria* spp. was also recorded. At the same time, *Laeviheterohelix dentata* a long ranging dominant species, decreases considerably reflecting a high stress environmental condition as warming. Palynological studies show an increase in fungal spore and in thermophilic species confirming the result gained from foraminiferal analysis.

Keywords: Late Maastrichtian; Global warming; Planktonic foraminifera; Central Alborz; Iran

Introduction

Recently most studies of Maastrichtian planktonic foraminiferal populations that aimed to describe the nature of important changes occurred in climate, weathering, sea level, and nature of the mass extinction focused in extraordinary details on the K-T transition that represents at best a few thousands years [1,2,32,30]. During Maastrichtian, a global cooling trend that began in the late Campanian was temporarily interrupted by a short warm event between 65.45 and 65.10 Ma. During this period intermediate and surface waters warmed by 3-4°C experienced by isotopic records [5,7,9,25,26,36, 45,48,46,24]. Climate changes have an extensive effect on planktonic foraminifera population, which are known to be extremely sensitive to changes in the physical and chemical properties of their surrounding waters [28]. Study of the Late Maastrichtian warm period in the Ziyarat-kola section provides some information for better understanding of planktonic population dynamics during the worldwide climatic changes. In this study, we examine responses of planktonic foraminifera and palynomorphs populations to the rapid climatic changes in the Late Maastrichtian.

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Material and Method

Location, Lithology and Procedures

The section studied is located eight km south of Ziyarat-kola village, south of Behshahr in northern flank of Central Alborz Mountains. At this locality (E: 53° 40′ 10″, N: 36° 30′ 51″) the section consists about 200m thickness of monotonous grey-green to light grey marl (Fig. 1). The very high rate of sediment accumulation in the studied area created a great potential for accurately evaluating the timing of environmental changes during the late Maastrichtian. A total of 85 samples were collected from the section, which were soaked in water with diluted hydrogen peroxide, washed through 63µm, 150µm and 250µm sieves, and dried until clean foraminiferal residues were recovered. About 200-300 individuals were picked up for each sample in two size fractions (63-150µm and >150µm) and mounted on dark cardboard slides for identification. These two size fractions were analyzed in order to obtain statistically significant representatives of the small and large groups. At the same time, the quantitative study of two populations splitted reduces the bias in first and last appearances due to the Signor-Lipps effect [43]. Species identifications are based on [8, 29, 39, 40, 33, 34].

Changes in Relative Abundance

63-150µm Size Fraction

During the cool climate intervals (both before and after the warm event) population of small species is dominated by *Hedbergella* spp., *Globigerinelloides asperus, Laeviheterohelix dentata* and *Heterohelix globulosa*. Within this group, *L. dentata* is the most abundant (~30%) in cool climate. and distinct decrease during warm period in Ziyarat-kola area (Fig. 2) [2,3] records the same planktonic foraminiferal quantitative data. Several species of planktonic foraminifera such as *Pseudoguembelina hariaensis, R. rugosa, Globigerinelloides subcarinatus* and *Globotruncana arca* which usually occur in >150µm size fraction are observed abnormally in 63-150µm size fraction (Fig. 2, Plate 1). Morphological features of the dwarfed specimen are similar or identical to normal sized adults, as indicated by the fully developed shape of chambers and apertures and the presence of a complete set of chambers and surface ornamentations. These dwarfed specimens decrease to only 7% of population in the upcoming cool period.

>150µm Size Fraction

The larger size (>150µm) planktonic foraminifera fraction dominated in warm period includes *Globotruncana arca, Globigerinelloides subcarinatus, Pseudotextularia intermedia, P. hariaensis, P. elegans* (Fig. 3). Within this group, the most faunal changes during the warm event include a marked increase in *P. hariaensis, G .arca* and *P. elegans* from 5% to over 10% and occasionally up to 25% showing an optimal condition for this species. In addition, a decline is recorded in *Rugoglobigerina penny, R. rugosa, Globotruncanita stuartiformis, Globotruncana dupeublei, Planoglobulina brazoensis,* and *Rosita* spp. but decreasing *R. rugosa* is dominant (from ~25% to ~3%) (Fig. 3). The end Cretaceous climate cooling before the

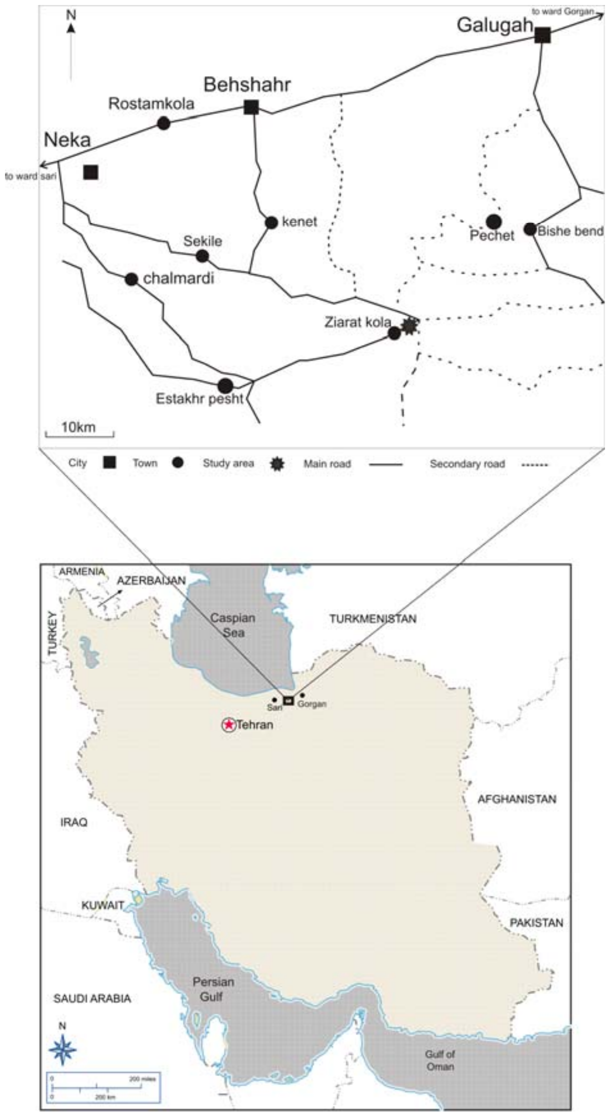

Figure 1. Location map of the studied area in the Behshahr, North of Iran.

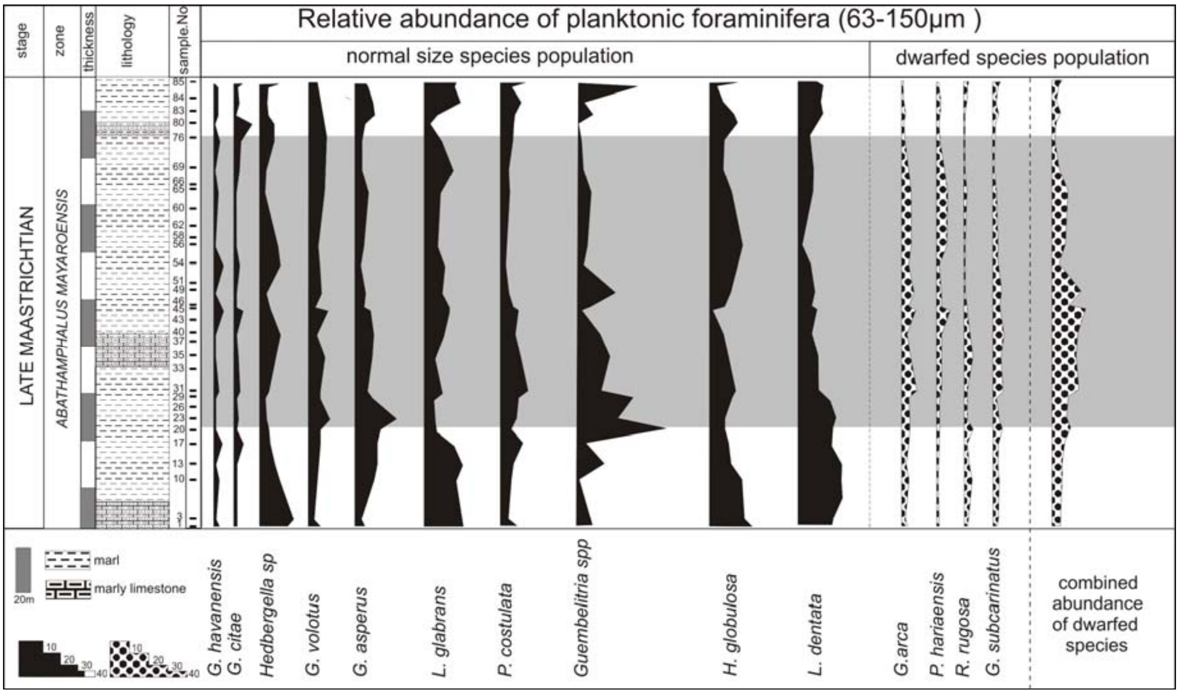

Figure 2. Abundances of Planktonic foraminifera species in the smaller size fraction (63-150µm) the Late Maastrichtian. Gray band marks the warm event associated with the abnormal appearances of dwarfed specimens.

K-T boundary is accompanied by major increase in larger plankton foraminifera (>150µm) such as *R. rugosa* (15%) and minor increases in *R. pennyi* (4%), *P. brazoensis* (8%) and *G. stuartiformis* (3%).

Diversity Trends

Planktonic foraminifera have been differentiated into two major groups, ecological specialists and ecological generalists [19, 20, 22, 38]:

1- Ecological specialists restricted to tropical and subtropical waters and with typically large and highly ornamented tests (e.g. globotruncanids, rugoglobigeri-nids, racemiguembelinids, and planoglobulinids). They are deep dwellers (in or bellow thermocline) and generally disappeared at or near the K-T boundary.

2- Ecological generalists characterized by smaller, sparsely ornamented, biserial and trochospiral test morphologies and with wide geographic distributions across latitudes (e.g. heterohelicids, globotruncanellids and guembelitrids). Statistical analyses in Ziyarat-kola section show that the ecological specialists population decreased in warm period of Late Maastrichtian (Fig. 4). Diversity shows the highest amount in >150µm fraction during the maximum cooling (before and after of warm event). Whereas during the warm period in the >150µm size fraction diversity averages decreased (Fig. 4). While its decrease at abundance percentage in cool water planktonic foraminiferal index such as heterohelicidae and Rugoglobigerina is other reason that confirms warm event [49]. In the 63-150µm size fraction, maximum diversity recorded corresponds to the warm interval and reflects appearance of dwarfed specimens. In addition, adult tests with larger and more complex morphologies have lesser tolerance limit to environmental stresses than juvenile forms. In contrast, younger species are generally abundant, small and simple morphologies and tolerate a wide range of stress environments. These factors resulted in increase in dwarfed species and juveniles in the warm interval [1].

[44] Believed that in stress conditions (warm period) asexual reproduction in plankton foraminifera change to sexual productivity, which causes smaller size of the tests.

Dwarfing

Macleod et al. quantified the test size reduction of *Heterohelix navarroensis, Guembelitria cretacea* and *Heterohelix globulosa* in late Maastrichtian and early Danian considerably reflecting the high stress environmental conditions. Dwarfing is the most striking response to the abrupt warming and occurred in various species of different morphologies and lineages (e.g.

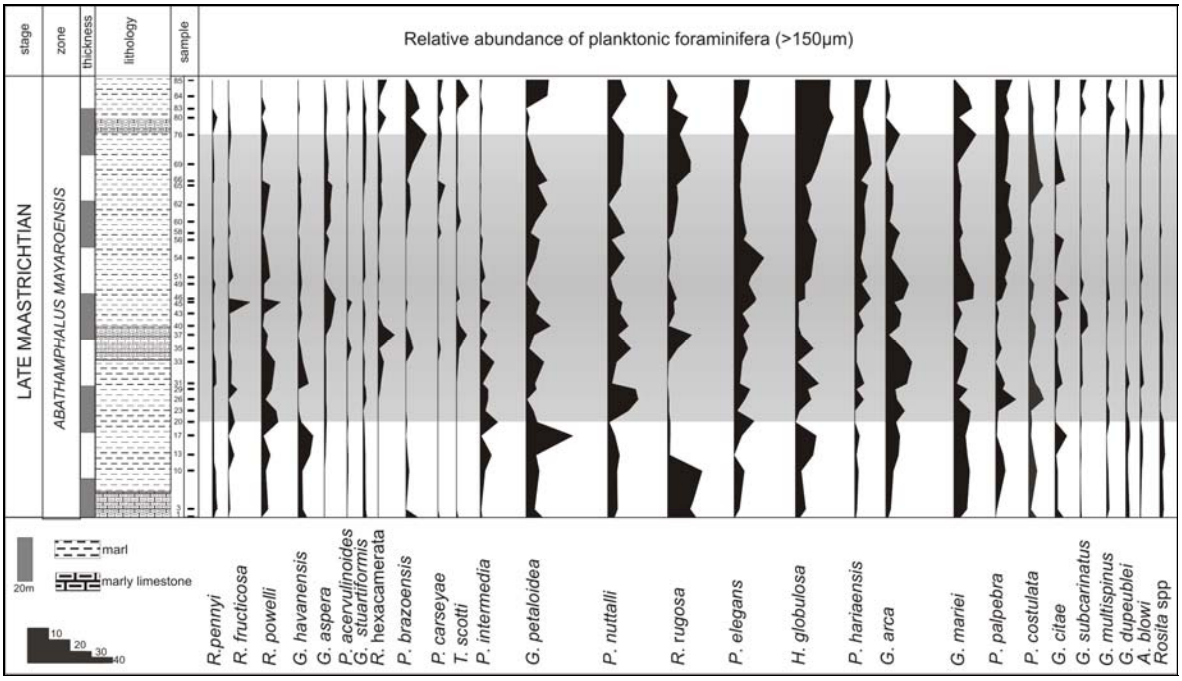

Figure 3. Abundances of Planktonic foraminifera species in the larger size fraction (>150μm) the Late Maastrichtian. Gray band marks the warm event. Note the marked increase of *Pseudoguembelina hariaensis*, *Globotruncana arca* and *Pseudotextularia elegans* in the warm interval. An opposite trend is recorded by some of species that decline in response to warming include in the tropical affiliated and *Rugoglobigerina rugosa* and several keeled globotruncanids.

biserial, trochospiral and keeled globotruncanids). It is a typical reaction to environmental stress conditions and is likely the result of increased reproduction rates. [11] recorded dwarfing of planktonic foraminifera species during the latest Maastrichtian and early Danian in Iran. In the studied area, dwarfing occurs in such species *G. subcarinatus, P. hariaensis*, *R. rugosa* and *G. arca* (Fig. 2).

Opportunist Species

Guembelitria spp. is interpreted as ecological opportunist (Pl. 2). They have been reportedly abundant in shallow neritic environments of the Maastrichtian from Denmark [41, 18], Kazakhstan [37], Tunisia [15-17]. Abundance of *Guembelitria* is also observed in uppermost Maastrichtian of the deeper outer shelf-upper bathyal of northern Tethys, e.g. Bulgaria [4] and Egypt [20].

At times of low species diversity and abundance, *Guembelitria* species tend to produce opportunistic blooms, as it is well known for the K-T boundary of Kabir Kuh in Iran [11]. High abundances of the ecological opportunist, *Guembelitria* characterize crisis in warm realms. The persistent relatively high abundances of *Guembelitria* spp. in shallow near shore areas suggest a high tolerance for salinity, nutrients and temperature fluctuations. At times of ecological stresses, ecological specialists disappeared, ecological generalists and opportunists thrived. The environmental conditions in which *Guembelitria* thrived occurred in shallow and deep-water environments, near shore and in the open marine oceans, at high and low latitude [19, 23]. *Guembelitria* blooms are therefore not specific to temperature, water depths or salinity but seems occur during times of low productivity, eutrophic waters and disruption of normal water mass stratification. In Ziyarat-kola section, noticeable increase in number of *Guembelitria* spp. confirms the global warming event (Fig. 2).

Palynological Evidences

An increase in thermophile fungal spores (>25%) which are related to warm and humid climate [14], along side with abundance of spore species *Cycadopites crassimarginis* produced by *Ginkgoals, Bennetitales* and *Cycadales* recorded in sample No.35 confirm the warm humid climates [42].

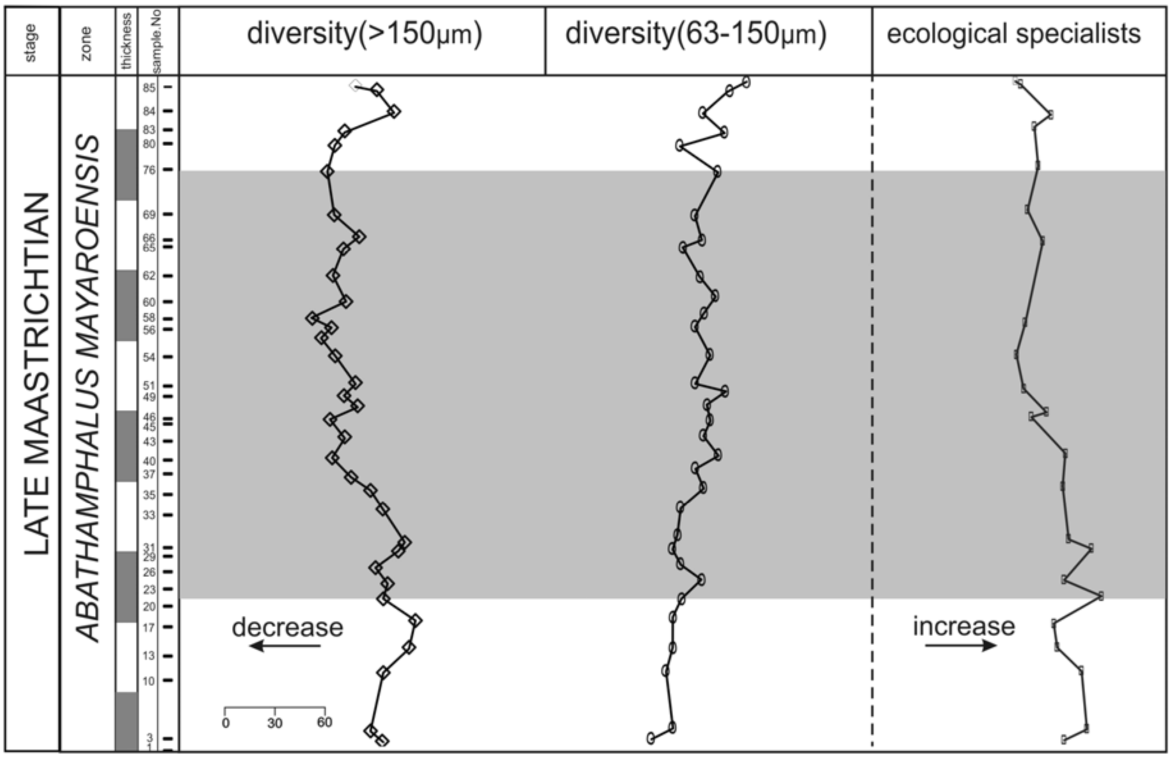

Figure 4. Planktonic foraminifera species diversity in the small (63-150µm) and large (>150µm) size fractions. Gray band marks the warming event. Increase in species diversity in the smaller size fraction during the warm interval is largely due to the presence of dwarfed specimens of species that are typically found only in the larger size fraction. In the >150 µm size fraction and in ecological specialists a decreasing trend is visible.

Results and Discussion

The upper Maastrichtian of low to middle latitudes was generally assigned to *Abathamphalus mayaroensis* Zone, 66.8 to 65 Ma [8, 39]. In the late Maastrichtian (during the last 500ky of the Maastrichtian), extreme and rapid climate fluctuations prevailed. Stable isotope data reveals that deep waters warmed rapidly by 3-4°C between 65.45 and 65.10 Ma followed by accelerated cooling during the last 100ky preceding the K-T boundary [25, 26, 45, 12, 6, 35, 37]. The cause of this global warming event is believed to be greenhouse warming due to a major pulse in Deccan Volcanism between 65.4 and 65.2 Ma. [13, 10, 47]. In fact, the end Cretaceous mass extinction began during the last 450 ky of the Maastrichtian and accelerated during the last 100ky of the Maastrichtian [21]. Salinity fluctuations indicate that during the short term global warming, high latitude deep-water production was significantly reduced and warm, saline, deep-waters flooded the ocean basins [19]. The observed changes in relative abundances of species, suggest a more complex and variable species response to climate warming. The species which are typically of large size (>150µm) show significant changes in relative abundance during the climate warming. Species with decrease abundances include the *R. rugosa*, *P. brazoensis* and *G. stuartiformis* and keeled globotruncanids (such as *Rosita* spp.) (Fig. 2). In contrast, some species populations remained apparently increased by the warm event as indicated by their continual dominance (e.g. *P. hariaensis, G. arca* and *P. elegans*). These species are typical components of mid-latitude planktonic foraminiferal assemblages [25]. The dominant presence of mentioned above species during the warm event at Ziyarat-kola, indicates that warming did not cause a massive retreat of the local mid-latitude population. A well-stratified water mass is a key factor for the existence of diverse plankton communities. Such conditions generally exist at low latitudes, where a warm layer overlies cooler and denser thermocline water mass that separate niches for surface and deeper planktonic dwellers. Warming of surface waters during the late Maastrichtian caused the water mass

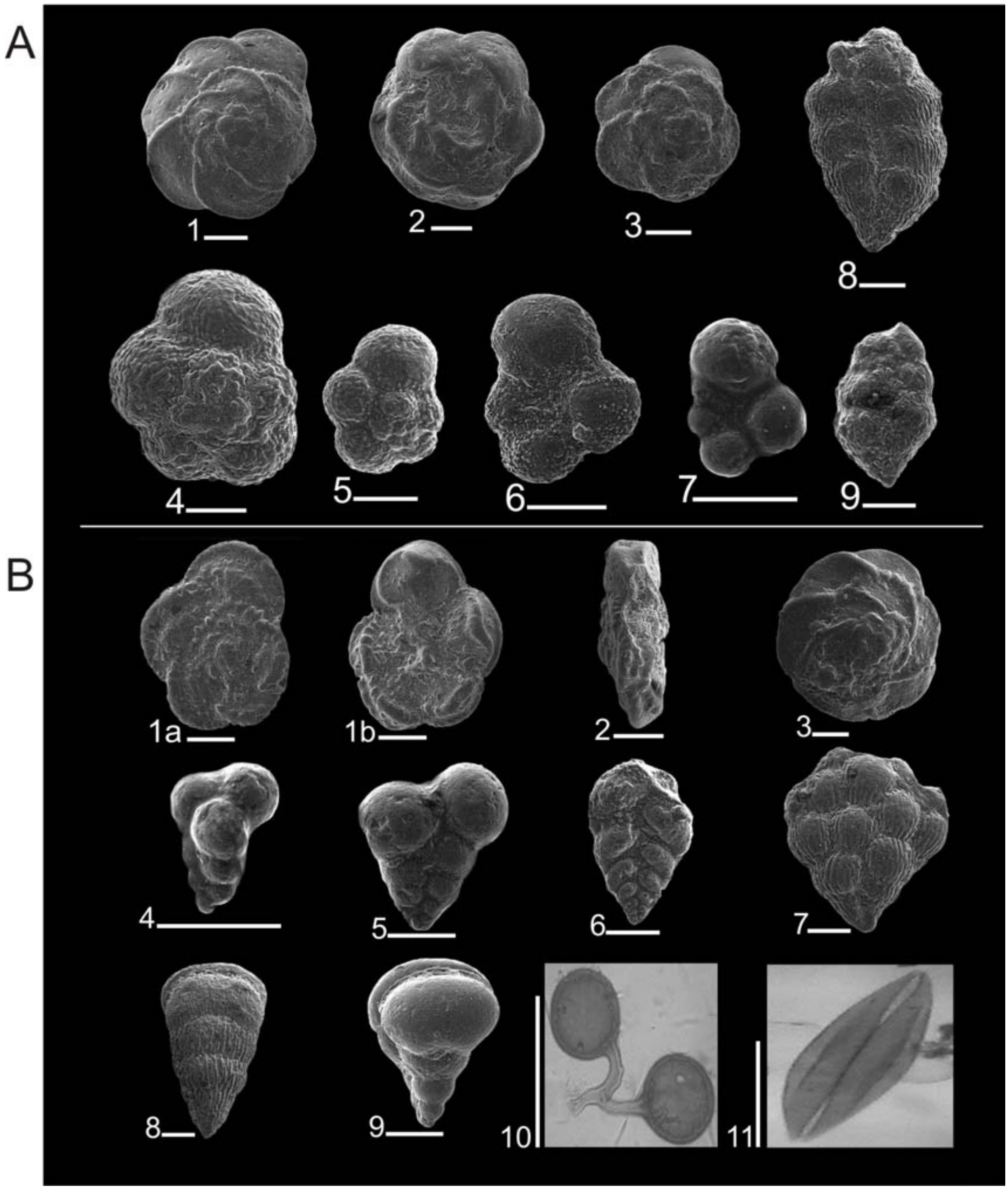

Plate 1. A: SEM illustrations of normal-sized adult and dwarfed planktonic foraminifera. Scale bar = 100 µm
Globotruncana arca (Cushman) (1-3), *Rugoglobigerina rugosa* (Plummer) (4, 5), *Globigerinelloides subcarinatus* (Brönnimann) (6, 7), *Pseudoguembelina hariaensis* Nederbragt(8-9).

1, 2. Normal-sized adult specimen (sample 11) 3. Dwarfed specimens (sample 43)
4. Normal-sized adult specimen (sample 10) 5. Dwarfed specimen (sample 35)
6. Normal-sized adult specimen (sample 2) 7. Dwarfed specimens (sample 69)
8. Normal-sized adult specimen (sample 11) 9. Dwarfed specimen (sample 37)

B: SEM illustrations of planktonic foraminifera. Scale bar = 100 µm

1a, 1b, 2. *Abathomphalus mayaroensis* (Bolli), 3. *Globotruncanita stuartiformis* (Dalbiez), 4. *Guembelitria* sp. (Cushman), 5. *Heterohelix globulosa*, (Ehrenberg) 6. *Laeviheterohelix dentata* (Suleymanov) 7. *Planoglobulina brazoensis (*Martin) 8. *Pseudotextularia elegans* (Rzehak) 9. *Pseudotextularia nuttalli* (voorwijk) 10. Fungal spores 11. *Cycadopites crassimarginis* (Dejersey).

stratification significantly reduced [26,7]. The reduction in upper water mass stratification is probably responsible for destroying the niches of planktonic dwellers and caused a sharp drop in the diversity of large planktonic foraminiferal population.

The triserials forms can live in environment with variable or extreme condition as exemplified by *Guembelitria cretacea* that survived the Cretaceous /Tertiary boundary event [33]. In Ziyarat- kola area increasing of *Guembelitria,* indicates crisis conditions in warm realm.

The present study suggests that several factors affected marine planktons during climate changing. Changes in water mass stratification, latitudinal and vertical migration, species competition and dwarfing may all have contributed to assemblage changes associated with climate warming.

The global climate-warming event between 65.45 and 65.10 Ma resulted in major changes in the structure of marine ecosystem during the Late Maastrichtian. The warming event was recorded in planktonic foraminifera and palynological content in Ziyarat-kola section during the Late Maastrichtian. The factors that confirm this event are as follows:

1) Increase in relative abundance of G. arca, P. hariaensis and P. elegans and decrease in P. brazoensis, G. dupeublei, and especially R. rugosa.

2) Dwarfism which is resulted from high stress environmental condition in which juvenile forms dominate as they are more tolerant than adult forms and from reproductive mode change from asexual to sexual caused high diversity in 63-150µm fraction.

3) Statistical analyses show decrease in ecological specialist with large and highly ornamented tests, which are sensitive against environmental factors.

4) Decrease in cool water species such as Heterohelicids and *Rugoglobigerina*.

5) Significant increase in opportunist species such as *Guembelitria cretacea,* which indicate unstable and high stress environmental condition.

6) Increase in relative abundance of fungal spores (>25%) and presence of spore species *Cycadopites crassimarginis* produced by plant, which grow in warm climate.

Acknowledgement

Authors thank Mr. Meysam Hemmati nasab for his kind cooperation

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Appendix A. Relative percent abundances of planktonic foraminifera in the size fraction >150µm (x<1).

distance from base(m)	0.0	3.4	21.2	28.7	37.9	44.2	49.3	54.5	59.1	61.9	71.7	78.0	84.0	88.3	94.2	99.3	101.1	107.5	110.8	119.8	128.4	131.5	136.6	144.3	153.3	155.6	163.3	176.7	184.6	188.9	194.8	201.8
Archeoglobigerina blowi			x	x	x		x		x	x	x				x				x				x					x	x	x	x	x
Globigerinelloides aspera				x	x	x	x	x	x	x	x	x	x	x	2	2	3	3	x		x	1	x	2	2	2	x	1	x	x	x	
G. multispinata	x	x	x	x		x	x		x	x	x			x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	2	x	1
G. subcarinatus		x		x		x				1	x	x	x	7	5	x		2	x			x						x	x	x	3	x
Globtruncana arca	2	3	5	7	8	6	14	6	6	12	17	13	2	8	9	5	10	12	11	4	6	8	3	4	4	3	1	8	1	2	3	1
G. mariei	4	6	7	7	6	7	8	4	7	3	6	7	2	3	5	3	9	9	8	4	4	5	4	4	4	4	3	10	4	8	7	2
Globotruncanella citae	x	x	x	x	x	x		x	x	2	x	x		1	2	x	4			x	x		x	x	3	1		x	x	1	1	1
G. havanensis	2	1	1	3	4	x	x			3	1	x		x	x	x	x	x	x	x	x		x	x	x	x				x		
G. petaloid	7	4	6	5	24	5	4	1	5	4	8	2	4	14	5	6	5	1	2	5	6	3	5	9	5	9	5	1	2	1	9	12
Heterohelix globolusa	4	6	4	8	9	2	4	8	7	13	3	9	4	3	4	3	6	6	8	9	10	8	7	8	6	8	10	13	15	21	20	19
Globotruncanita dupeublei	x	x	x	x	1	x	x	x	x	x					x	x					x	x					x			x	x	
G. stuartiformis	x	x	x	x	x	x		x	x	x	x		x	x	x	x			x	x	x	x			x	x	x	x	x	x	x	
Planoglobulina acrevulinoides			x	x		x						x				x									x			x		x	x	
P. brazoensis	3		x	x		x					2	x			x							x	x	1	1	x	2	5	1	4	3	x
P. carseyae	x											x								x		x	2		x	1	x	1	x	x	1	x
Pseudoguembelina costulata	3	1	3	2	1	1	1	5	3	2	1	1	2	2	1	1	2	2	1	2	2	1	1	1	5	4	3	2	2	2	1	1
P. hariaensis	x	x	x	x	1			2	x	2	x	x	x	2	1	3	4	2	3	1	2	3	3	2	3	2	4	3	2	2	3	4
P.palpebra	x	x	3	2	x	x	x	5	2	2	x	2	x	x	x	x	2	3	3	4	2	4	4	3	4	2	3	4	2	4	3	4
Pseudotextularia elegans	3	4	6	2	5	10	4	6	8	5	5	7	6	8	5	14	13	8	9	13	6	7	6	5	5	5	5	8	5	6	7	8
P. intermedia	1	x	2	5	x	8	2	4	4	1	6	x	3		1	5	x	x	2	x	1		x	x		x	x	x	x	1		x
P. nuttalli	3	4	3	4	3	1	6	9	8	2	3	7	4	6	4	5	3	2	1	6	2	5	4	1	4	4	5	8	2	4	7	5
Racemiguembelina fructicosa		x		2		2	1		2	x	x	x	x	x	x	6	x		1	x		x		x	x			x	x	x		
R. powelli		2	1	3	x	8	7	1	4	4	5	1	2	x	1	7	x	x	3	2	1	x	1	2	3	x	x	2	1	x		
Rosita spp	1	1	x	2	1	1			x	x	x	x	x	x								x					x		1	x		
Rugoglobogerina hexacamerata									x	x	2	x	4	1		x			x		x	x	x	1	x	1	1	x	2	x	x	2
R. pennyi	x	x	x							x	x			x	x				1			x	x			x	x	x	1			
R.rugosa	22	8	24	x	1	1	x	x	x	x	x	3	8	x	2	2	3	1	x	1	x	2	4	8	3	10	10	4	7	2	3	x
Trinitella scotti	x										x	x	3	1			x					1	x	x	x	x	x			x	3	x
total number counted	219	256	267	248	249	366	206	220	301	252	248	268	220	202	210	294	235	206	228	271	256	220	254	253	402	363	346	276	333	280	321	305

Appendix B. Relative percent abundances of planktonic foraminifera in the 63-150μm size fraction (x<1).

distance from base(M)	0.0	3.4	21.2	28.7	37.9	44.2	49.3	59.1	61.9	78.0	88.3	99.3	101.1	107.5	119.8	128.4	153.3	163.3	176.7	184.6	188.9	194.8	201.8
G.aspera	x		3	3	4	4	8	2	1	3	3	2	x	1		x	2	x	x	x	3	3	2
G.subcarinatus	1	2	2	2	2	3	2	1	4	4	6	6	3	8	X	x			x	x	2	1	2
G.volotus	3	1	2	2	3	3	5	3	3	4	2	4	1	3	3	2	4	4	3	3	1	3	1
G.aegyptiaca	x		x	x		x	x		1	x		1		x			x		x		X	1	
G.havanensis	x		x		1				x			2	1		2		x		x		X	x	x
G.citae				1		x		x	x		2			x				x	1	3		x	x
G.cretacea	x	7	2	10	4	32	15	21	9	12	9	3	6	15	3	5	6	3	3	2	7	3	22
Hedbergella sp	7	10	4	3	1	1	0		x	3	4	2	1	x	4	4		x	3	3	1	1	1
H.dentata	17	24	22	17	23	13	15	16	12	9	7	9	7	8	6	4	9	8	6	5	18	15	19
H.globulosa	23	22	22	18	18	17	17	19	20	18	16	13	17	19	20	22	19	17	17	21	20	16	15
keeled	2	1	2	1	2	3	3	2	6	3	2	5	2	4	2	3	3	2	1	x	1	x	x
L.glabrans	16	12	10	14	9	5	5	4	6	5	7	8	8	6	7	5	6	9	6	4	5	11	9
P.costulata	5	2	3	4	7	3	5	6	9	6	4	5	4	2	1	2	3	2	4	4	4	6	3
P.hariaensis								x	x	x	3	x	x		2	3	2	x		x	x		
P.elegans					x		x		x		x		x		x		x						
R.rugosa	x	x	2	1	x	3	x	x	x	3	1	x	x				x					x	x
dwarfed species population	3	4	5	5	6	7	6	7	11	10	11	14	7	12	3	6	7	4	2	3	4	3	4
total number counted	155	215	193	211	224	192	217	180	190	181	200	194	170	183	150	185	135	162	170	237	152	143	279

Appendix C. Relative abundance species diversity and relative percent abundances species ecological specialist in the size fraction >150μm and 63-150μm.

distance for base (m)	diversity (150μm)	diversity (230μm)	ecological specialist (%)
202.9	36	34	29
201.8	38	32	30
194.8	44	27	33
188.9	38	30	32
184.6	3	24	34
176.7	40	29	33
163.3	44	26	35
155.6	42	23	34
153.3	43	21	35
144.3	39	24	36
136.6	40	25	35
131.5	44	22	34
128.4	42	26	34
119.8	39	28	34
110.8	40	26	33
107.5	41	25	37
101.1	37	23	35
99.3	42	28	39
94.2	38	27	36
88.3	37	29	38
84.0	45	26	40
78.0	43	27	46
71.7	41	24	45
61.9	44	20	44
59.1	45	23	41
54.5	42	24	40
49.3	43	19	38
44.2	45	21	41
37.9	51	24	43
28.7	50	25	47
21.2	45	22	51
3.4	43	23	50
0.0	45	20	45