Campanian and Maastrichtian Biostratigraphy and Paleoenvironment in Jorband Section, North of Iran

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Abstract

The study of planktonic foraminifera in Jorband section reveals two major events in Campanian- Maastrichtian boundary and early-late Maastrichtian biodiversification. In this study, occurrence and species richness of planktonic foraminifera in Jorband area show the warm marine environment dominant during early to late Campanian and it could be correlating by tropical and subtropical biozones. The warm condition converted to rapid cooling exactly in Campanian-Maastrichtian boundary. This rapid changing in temperature was not important effecting in extinction species but make important differences in number of species. Increasing the heterohelicids populations associated with surface dwellers and decreasing of globigerinids show the rapid regression in Jorband area in the Campanian-Maastrichtian boundary. The cooler condition is dominated during early Maastrichtian, whereas heterohelicids were associated by rugoglobigerinids and globigerinelloids. In the late Maastrichtian, abundances of double-keeled species show high sea level and warmer condition dominated in Jorband area in Planoglobulina brazoensis zone (CF5) and Racemiguembelina fructicosa zone (CF4).

Keywords: Campanian-Maastrichtian biostratigraphy; Climate; Planktonic foraminifera; Alborz Mountains; Iran

Introduction

Alborz Mountains plays an unique role in paleoenvironment and geologic history of Iran. In some parts of northern flanks of Alborz, an oceanic crust has been found that related to many volcanic activities in other parts of Alborz during in Cretaceous [63], [64], [12], [6], [19], [65], [14], [22], [23] Volcanic activities and ocean floor spreading stopped in Coniacian-Santonian in the most part of Alborz [65], [23] and

Campanian deep and warm sea dominated in Alborz. Campanian- Maastrichtian sediments formed mostly from light marl and marly limestone that enclosed abundant planktonic foraminifera.

Planktonic foraminifera did not suffer significant extinction across the Campanian-Maastrichtian and early-late Maastrichtian boundaries but their population relative changes might be show the environment temperature fluctuation during the Campanian and Maastrichtian. For more recognition of climatic and

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environmental history of late Cretaceous in Alborz, a section investigated in less forestry part of northern part of Alborz. The main objective of this study determine the biostratigraphy, provide age control for the Campanian- Maastrichtian rocks and reconstruct the environmental history of Alborz basin based on planktonic foraminifera and correlation and comparison of faunal and climatic events with global trends.

There are a few published studies on Cretaceous planktonic foraminifera of the Northern flanks of Central Alborz Mountains in Iran. The Jorband area, which spans Mesozoic and Cenozoic sediments, has been studied first time by [63], [64]. A geological investigations reported by [11], [12], [13] and [19] and descriptive geological map of northern flanks of Alborz Mountains. A brief geological study of Central Alborz Mountains was published by [65]. In this area [23] reported the Campanian-Maastrichtian transition based on foraminiferal stratigraphy. Because of forestry covered, the Cretaceous outcrops are not more distinctive. An almost complete Upper Cretaceous sedimentary sequence was not recovered by drilling of N.I.O.C.

Material and Methods

91 samples both hard and soft were taken from Jorband section. Thin sections were prepared from hard rocks and the soft samples preparation followed standard techniques described in [36]. Samples were crushed to little particles (2-3 cm diameters), soaked in tap water with diluted hydrogen peroxide 10%, cleaned in an ultrasonic bath, wet-sieved through 63 μ m sieve and dried. After drying, foraminifera were picked and were studied under a reflected light microscope in the paleontological laboratory of Tehran University and using the scanning electron microscope (SEM) at Razi Metallurgy Research Center for taxonomic purposes and to assess the state of preservation on a micron scale.

Planktonic foraminifera are common to abundant and relatively well preserved though recrystallized. Species were identified following [18], [50] and [47]. Marker species and the most common species are illustrated (Plates 1-5).

Location and Lithology

A few Upper Cretaceous sediments that exposed in North of Iran mostly formed by the milky to light grey marl lies on Northern flanks of central Alborz Mountains. The Jorband section of this report is located in about 28 Km south of Noor city (across the shore line of Caspian Sea). The Lavij River crossed the section and the Cretaceous sediments outcrops on both sides of the river (Fig. 1). The Lower part of the Jorband section consists of light dark gray, well bedded limestone with the age of Cenomanian [22]. The upper boundary truncated by West-East fault and covered with vegetation.

Lithologically, the Jorband section consists of 333 m alternation of marly limestone, marl and calcareous marl. Generally, this unit is of green-gray to dark-gray weathered color and deposited in open marine environment during Campanian-Maastrichtian.

Biostratigraphy

Previous studies of Cretaceous planktonic foraminiferal biostratigraphy is generally used the zonation of [18]. This zonal scheme divides the Campanian and Maastrichtian into seven biozones. *Globotruncanita elevata, Globotruncana ventricosa, Radotruncana calcarata* zones present the Campanian



Figure 1. Location map studied area and Jorband section, North of Iran.

stage	This	study	Li et al., 1999	age (Ma)	Li & Keller, 1998a, b	State 1	Caron, 1985	stage	Sliter, 1989	ttege	Nederbragt,	stage	Robaszynski & Caron 1995	stage	Hardenbol et al, 1998	stage	Ghourchaei, 2006	stage	Coccioni et al, 2006	stage	Odin & Lamourelle, 2001 Tercis, France		stage	Gradstein et al, 1995 Europe	substage
fus	datum events	zones	Tunisia		Tunisia	- and -		las -	Tethys	sub	El Kef, Tunisia	dus .	Tethys	dars	Tethys	1	SW. Iran	sub	Tethys	ta	Planktonic foraminiferal zones	Ammonite zones	â	Ammonite zones	
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Early Maastrid	L C. contusa	Gansserina gansseri (CF7)	Gansserina jansseri (CF7) Gansseri (CF7)	69.6	Gansserina gansseri (CF7)	09.6 g	gansseri	La	gansseri	E. Maa	Gansserina gansseri	astrichtian	gansseri	E. M	gansseri	htian	Gansseria gansseri	trichtian	Gansserina gansseri	Н	Rugoglo Contusot	neubergicus	Ma	Neubergieus tridens	Early Maastric
E. Campanian M. Campanian Late Campanian	at 0. gainsen	Planoglobolina carsevae(CF8b)	Rugoglobigerina hexacamerata		Globotruncana aegyptiaca (CF8)	Campanian 0.12 2.2.5 Early Maastrichtian	Globotruncana aegyptiaca			1		r Ma:		Campanian		stric		Tas		11	Globotruncanella havanensis				l ~
	A. mayaroensis	Globotruncana aegyptiaca (CF8a)	(CF86) Globotruncana aegyptiaca (CF8a)	71.0				Maastrichtia	Globotruncana aegyptiaca Globotruncanella havanensis Radotruncana calcarata	Campanian		Early	Globotruncana aegyptiaca		Globotruncana aegyptiaca	Early Maa	Globotruncana aegyptiaca	Early !	Globotruncana aegyptiaca			hayatti			
	R. calcarata	Globotruncanella havanensio (CF9)	Globotruncanella subcarinatus (CF9)	otruncanella bearinatus (CF9) 74.0	Globotruncanella suboarinatus (CF9)		Globotruncanella havanensis	Early		Globotruncanella havanensis		Globotruncanella havanensis	Late C	Globotruncanella havanensis		Globotruncanella havanensis		Globotruncanella havanensis	ו				1		
	. R. colcorate	Radotruncana calcarata (CF10)	Radotruncana calcarata (CF10)		Radotruncana calcarata (CF10)		Radotruncana calcarata	L. Campanian			Radotruncana calcarata	Campanian L. Campanian	Radotruncana calcarata		Radotruncana calcarata	L. Campanian	Radotruncana calcarata	L. Campanian	Radotruncana calcarata	Campanis	Radotruncana calcarata		Campanian	Hayatti	Late Campani
	. G wettions	Globotruncana ventricosa	NO data		NO data		Globotruncana ventricosa	M. Campanian	Globotruncana ventricosa	Globotruncanita subspinossa	M. Campanian	Glopotruncana ventricosa M. Campanian	Globotruncana ventricosa	M. Campanian	Globotruncana ventricosa	M. Campanian	Globotruncan ventricosa		a ventricosa / ina rugosa	polyplocum					
	⊥ G. elevata	Globotruncanita elevata					Globotruncanita elevata	E. Campanian	Globotruncanita elevata	E. Campanian	Globotruncanita elevata	Globotruncanita elevata	E. Campanian	Globotruncanita elevata	E. Campanian	Globotruncanita elevata	E. Campanian	Globotruncanita elevata		Globotrunca Rugoglobige	pseudoxybeloceras				

Figure 2. A comparison of the Campanian-Maastrichtian zonal scheme proposed in this study and the important standard zonations of various authers based on planktonic foraminifera and ammonites.

age and Globotruncanella havanensis, Globotruncana aegyptiaca, Gansserina gansseri and Abathomphalus mayaroensis zones belong to the Maastrichtian.

A more exact zonal scheme for the Upper Cretaceous has been proposed by [42], [45]. They proposed to divide the Maastrichtian into eight biozones labeled CF8 to CF1 (CF= Cretaceous Foraminiferal zones) and calibrated them to the paleomagnetic time scale of DSDP Site 525A. This new zonal scheme was subsequently applied successfully to sections in Tunisia [1], [2], [43], [45], [46]; Bulgaria [5]; Egypt [66], [39] and Iran [27]. The new zonal scheme is particularly applicable to the Madagascar planktonic foraminiferal assemblages because it was originally based on South Atlantic DSDP Site 525A, located at the same paleolatitude as Madagascar.

This biozonation provided a significantly higher biostratigraphic resolution than previous zonal schemes as applied in this study (Fig. 2). Biozonation used in this study is similar to the [45], except *Pseudotextularia intermedia* (CF5), *Rugoglobigeria hexacamerata* (CF8b), and *Globigerinelloides* (*Globotruncanella*) *subcarinatus* (CF9) zones are here replaced by *Planoglobulina brazoensis*, *Planoglobulina carseyae* and *Globotruncanella havanensis* zones respectively. We also used [18], [56] planktonic foraminifera biozonation for early-middle Campanian.

Globotruncanita elevata Zone

This zone marks an interval from the FA of G.

elevata at the base and the FA of the Globotruncana ventricosa at the top of the biozone. The identified species are: Archaeoglobigerina blowi, A. basquensis, A. cretacea, Globotruncana arca, G. bulloides, G. lapparenti, G. linneiana, Globigerinelloides ultramicra, Hedbergella holmdelensis, Heterohelix carinata, H. globolusa, H. navaroensis, H. punctulata, H. striata, H. turjida, Marginotruncana pseudolinneiana, Pseudotextularia nuttalli, Contusotruncana fornicata.

This zone contains 29.8 m. of marly limestone and calcareous marl and early Campanian is assigned to this zone.

The proposed stratigraphic zonation in this study corresponds with some zonal schemes from different localities such as the standard biozones introduced by [18], [42], [43], [45] and [50] for tropical and subtropical Cretaceous deposits, specially Tethian domain, and the introduced planktonic foraminifera and ammonite zones together at different Tethian areas and Europe. A correlation of some Campanain-Maastrichtian zonal schemes based on planktonic foraminifera is also outlined in Figure 2.

Globotruncana ventricosa Zone

This zone is defined by the FA of *G. ventricasa* at the base and FA of *Radotruncana calcarata* at the top of this biozone [18], [21], [56]. The associated planktonic foraminifera are *Archaeoglobigerina cretacea*, *A. blowi*, *Globotruncana arca*, *G. bulloides*, *G. lapparenti*, *G. linneiana*, *Globotruncanita elevata*, *G. stuartiformis*,

Heterohelix carinata, H. globolusa, H. navaroensis, H. striata, H. turjida, Pseudotextularia nuttalli.

This zone has 103.4 m alternation of calcareous marl, marl and marly limestone and presents the middle Campanian.

Radotruncana calcarata Zone (CF10)

This zone is defined by the FA of *G. ventricasa* at the base and FA of *Radotruncana calcarata* at the top of this biozone [18], [21], [56]. The associated planktonic foraminifera are *Archaeoglobigerina cretacea*, *A. blowi*, *Globotruncana arca*, *G. bulloides*, *G. lapparenti*, *G. linneiana*, *Globotruncanita elevata*, *G. stuartiformis*, *Heterohelix carinata*, *H. globolusa*, *H. navaroensis*, *H. striata*, *H. turjida*, *Pseudotextularia nuttalli*.

In Jorband section, Zone CF10 contains 94.8 m alternation of marl, calcareous marl and marly limestone and marks the earliest of late Campanian.

Globotruncanella havanensis Zone (CF9)

This zone marks the interval from the LA of Radotruncana calcarata at the base and the FA of Globotruncana aegyptiaca at the top. [56] and [18] believed that the base of G. havanensis zone informally marks the Campanian-Maastrichtian boundary in low latitudes. This zone is equivalent to Globotruncanella (Globigerinelloides) subcarinatus Zone of [42], [43] and [45] whereas the G. havanensis was not found. However, in Jorband section G. havanensis and G. subcarinatus were found together. Accompanying species recorded are Archaeoglobigerina cretacea, A. blowi, Globigerinelloides ultramicra, Globotruncana arca, G. bulloides, G. lapparenti, G. linneiana, G. ventricosa, Globotruncanella petaloidae, G. subcarinatus, Gublerina acuta, Hedbergella holmdelensis, Heterohelix globolusa, H. navaroensis, H. punctulata, H. striata, Planoglobulina riograndensis, Pseudotextularia elegans, Contusotruncana fornicata, Rugoglobigerina rugosa.

In studied section, this zone consists of 22.5 m of marl and could be considered as the late Campanian.

Globotruncana aegyptiaca Zone (CF8)

CF8 Zone is defined by FA of *Globotruncana aegyptiaca* at the base and FA of the *G. gansseri* at the top. This zone is subdivided into two subzones (CF8a and CF8b) to yield a higher resolution time control [44], [45].

Globotruncana aegyptiaca Subzone (CF8a)

CF8a Subzone is defined by the FA of the index taxon G. aegyptiaca at the base and the FA of P. carseyae at the top of Globotruncana aegyptiaca Subzone in the study area. The associated planktonic foraminifera are Abathomphalus mayaroensis, Archaeoglobigerina blowi, A. cretacea, Globotruncana, G. mariei, G. ventricosa, Globotruncanella petaloidae, G. subcarinatus, Globotruncanita stuarti, G. stuartiformis, Hedbergella holmdelensis, Heterohelix globolusa, H. navaroensis, H. punctulata, H. striata, P. riograndensis, Pseudotextularia elegans, P. intermedia, P. nuttalli, Pseudoguembelina costulata, Contusotruncana fornicata, Rugoglobigerina macrocephala, R. milamensis, R. penneyi, R. rogusa, R. rotundata, Ventilabrella eggeri.

Further more, variety and abundances of rugoglobigerinid and heterohelicid and lithology changes from marly limestone in CF9 to marl in CF8a could be separate the upper and lower boundaries of this subzone.

Subzone CF8a spans 19 m. of marl and latest Campanian is assigned to this zone (Fig. 3).

Planoglobulina carseyae Subzone (CF8b)

The *Planoglobulina carseyae* or CF8b Subzone is defined by FA of *P. carseyae* at the base and the FA of the *Gansserina gansseri* at the top of subzone. This interval is equivalent to the *Rugoglobigerina hexacamerata* Subzone (CF8b) of [45]. In this study we rename this subzone to *Planoglobulina carseyae* Subzone because this species first appears in the Jorband section at the base of CF8b but *R. hexacamerata* is diachronous [44], [45] and first appears at the top of CF9 in this study (Fig. 3).

The Campanian-Maastrichtian boundary in Jorband section similar to other parts of the world has not been defined by planktonic foraminifera. In Jorband, follow the [44], [45] studies; we placed the Campanian-Maastrichtian boundary at the base of *P. carseyae* Subzone. The associated planktonic foraminifera are *Globotruncana aegyptiaca, G. mariei, G. ventricosa, Globotruncanella petaloidae, Globotruncanita stuarti, G. stuartiformis, Gublerina acuta, Pseudoguembelina intermedia, P. nuttalli, Contusotruncana fornicata, Rugoglobigerina hexacamerata, R. rugosa.*

Subzone CF8b spans 9.5 m of marl and considered at earliest Maastrichtian.

Gansserina gansseri Zone (CF7)

This zone is defined by the FA of Gansserina



Figure 3. Distribution of planktonic foraminifera from the Campanian-Maastrichtian succession of Jorband section in order to first and last appearances.

gansseri at the base and FA of *Contusotruncana* contusa at the top of the biozone. Because of the *Abathomphalus mayaroensis* is diachronous and mostly rare or absent in continental shelf and neritic zone [42], [44], [50], [37] and also in this section is found earlier than the *G. gansseri*, we have not used the *A. mayaroensis* as a zonal marker to determine the top of Zone CF7.

The dominated species in this zone are Globotruncana mariei, G. ventricosa, Globotruncanella subcarinatus, Globotruncanita subspinosa, Heterohelix globulosa, H. navaroensis, Pseudoguembelina costulata, P. riograndensis, Pseudotextularia elegans, Rugoglobigerina hexacamerata and R. rugosa.

This zone spans 26 m of marl and an early Maastrichtian is assigned to this biostratigraphy unit.

Contusotruncana contusa Zone (CF6)

Zone CF6 is defined by the FA of the Contuso-

truncana contusa at the base and the LA of Globotruncana linneiana at the top of the biozone. Associated species are as follow: Gansserina gansseri, G. weidenmayari, Globotruncana ventricosa, Contusotruncana fornicata, Rugoglobigerina hexacamerata, R. milamensis, R. rugosa, Pseudotextularia elegans, P. intermedia, P. nuttalli, Ventilaberelle eggeri.

In section studied this zone consists 15.5 m of marl and early Maastrichtian assigned to this zone.

Planoglobulina brazoensis Zone (CF5)

This zone is defined by the last appearance of *Globotruncana linneiana* at the base and the first appearance of *R. fructicosa* at the top of the biozone. This zone is equivalent to the *Pseudotextularia intermedia* Zone of [42], [44]. They believe *P. intermedia* appeared in Zone CF6 but well-developed typical morphotypes of this species appear in CF5 [42]. However, we rename this zone to *P. brazoensis* Zone,

which first appears in CF6 Zone, but well developed typical morphotypes of this species appear in CF5 Zone. On the other hand, in Jorband section, *P. intermedia* was found in Zone CF10, in Campanian. Associated species are *Abathomphalus mayaroensis*, *Gansserina* gansseri, *G. weidenmayeri*, *Gumbelitria cretacea*, *Planoglobulina acervulinoides*, *Pseudotextularia elegans*, *P. intermedia*, *Contusotruncana contusa*, *C. patelliformis*, *Rugoglobigerina milamensis* and *R. pennyi*.

This zone spans 7.5 m of marl and could be considered as the topmost parts of early Maastrichtian (Fig. 3).

Racemiguembelina fructicosa Zone (CF4)

This zone is defined by first appearance (FA) of *R. fructicosa* at the base of biozone. Due to the absence of *Pseudoguembelina hariaensis* in the study area, the upper limit of this zone is not exactly distinguished. In some zonal schemes, the first appearance of *R. fructicosa* informally marks the upper Maastrichtian boundary [2], [4], [45], [46]. We have continued the practice of placing the lower-upper Maastrichtian boundary at the *R. fructicosa* first appearance following the [46]. Associated species are *Abathomphalus mayaroensis, Globotruncanita conica, Gublerina cuvillieri, Planoglobolina acervulinoides, P. brazoensis, P. carseyae, Racemiguembelina powelli, Contusotruncana contusa* and *C. walfischensis.*

Zone CF4 encompasses 5 m of marl and early upper Maastrichtian is assigned to this zone.

The Campanian-Maastrichtian Boundary

In spite of different considerations about Campanian-Maastrichtian boundary, this boundary has not exactly defined.

[28] proposed that the Campanian-Maastrichtian boundary be placed at the top of the *Baculites jenseni* ammonite Zone, or possibly the overlying *B. eliasi* based on macrofossil and strontium isotope correlations between the Kronsmoor Section of Germany, the English Chalk and the United States Western Interior [41], [48]. Based on linear interpolation between K/Ar ages of two bentonites at 70.1 \pm 0.7 Ma and 73.2 \pm 0.7 Ma, [28] estimated an age of 71.6 \pm 0.7 Ma for the Campanian-Maastrichtian Stage boundary. However, at Tercis section, near Dax, southwestern France, The first appearance (FA) of the ammonite *Pachydiscus neubergicus* was introduced as the marker of C-M boundary as compare with planktonic foraminifera identified in this section simultaneous with FA of *Rugoglobigerina scotti* and *Contusotruncana contusa* in 72 Ma [51], [52]. Also [33] have placed the C-M boundary at the FA of *Pachydiscus neubergicus* in northeastern Mexico. [46] informally used the planktonic foraminiferal datum of *Rugoglobigerina hexacamerata* and *Planoglobulina carseyae* at 71 Ma for the Campanian-Maastrichtian boundary based on biostratigraphic correlation with the geomagnetic time scale at DSDP site 525 in northwestern Tunisia. This datum event is within the range of [28] estimate of 71.6±0.7 Ma for this boundary.

[68] placed the Campanian-Maastrichtian boundary in the FA datum of *Rugoglobigerina pennyi*. This taxon was recorded throughout the Maastrichtian but not in the Campanian, and may thus prove to be a good marker for Maastrichtian [62]. However, informal reports proposed that this boundary be placed at the FA of *G. gansseri*, or LA of *G. calcarata* [42], [67]. Some of the reports suggest that the FA of *P. neubergicus* and the *B. eliasi* Zone predate the FA of *G. gansseri* and postdate of the LA of *G. calcarata*. Also the FA of the *R. contusa* reported simultaneous with FA of *P. neubergicus* in Tercis, France [51, [52], [20] whereas in other places as Tunisia [42], [43], [46], Iran [22], Kerguelen Plateaus South Indian Ocean [53] appeared later.

Planktonic foraminiferal workers have generally placed the Campanian-Maastrichtian boundary at the top of the *G. calcarata* Zone [56], [18], [55], [42], [43].

In spite of simultaneous of introduced biozones with [46] and because of diachronous appearance of R. *hexacamerata* [45], [46] that first appears in G. *havanensis* biozone (CF9) in this study, we placed the FA of P. *carseyae* for Campanian-Maastrichtian boundary.

The Early-Late Maastrichtian Boundary

This boundary has not clearly defined. Although, at the Brussels meeting it was recommended that the Maastrichtian stage be formally divided into two sub stages, early and late, [42], [45], [46] there is still no formal agreement as to the placement of the early-late Maastrichtian boundary.

Planktonic foraminiferal workers have generally placed this boundary at the FA of *G. gansseri* [56], [18], [42], [43]. [16] proposed that the early-late Maastrichtian boundary be placed at the FA of *A. mayaroensis*, though informal reports have placed this boundary at the FA of *R. fructicosa* [50], [44], [46], [2], [4].

However, *A. mayaroensis* is diachronous and appears earlier in high latitudes [16], [34], [32], [42], [43], [44],

[46], [3], [54] and is rare or absent in neritic environments [34], [58], [35], [17], [44].

[28] estimated the early-late Maastrichtian boundary at 69.5 Ma that corresponds to the FA of *C. contusa* at DSDP site 525 in Tunisia where studied by [42].

In this study, we accept the practice of informally placing the early-late Maastrichtian boundary at the FA of *R. fructicosa* following [2], [3], [45], [46], [50].

Paleoecology

[4], considered carbon and oxygen isotope ranking of planktonic foraminiferal species from late Campanian to late Maastrichtian intervals, described deep (subthermocline), thermocline, and mixed layer habitats (surface and subsurface). Surface and deep-water habitats were occupied by relatively few species (deep dwellers: Planoglobulina multicamerata, Heterohelix Abathomphalus rajagopalani, mayaroensis, Globotruncanella havanensis, Gublerina cuvillieri and Laeviheterohelix glabrans; surface: Pseudoguembelina species). Most species occupied subsurface depth, though assemblages varied between the thermocline layer and the subsurface mixed layer during cool and warm intervals. During cool climate intervals, keeled globotruncanids and perhaps Globigerinelloides and Racemiguembelina occupied the thermocline layer, whereas Rugoglobigerina. Pseudotextularia, Planoglobulina and heterohelicids inhabited the subsurface mixed layer. [39] named this group as ecological specialists (E.S.), except heterohelicids, and proposed that the diversity of E.S. was highest in tropical and subtropical environments. Planoglobulina multicamerata and Heterohelix rajagopalani as thermocline (deep water) indicators, that were generally restricted to low latitudes [4] are absent in Jorband section and Abathomphalus mayaroensis, Gansserina gansseri and Laeviheterohelix glabrans, as deep dwellers, were rare similar to Gumbelitria cretacea which was rare in open marine environments during the Maastrichtian [40].

Globotruncanids are usually regarded as intermediate to deep dwellers and geographically limited to the Tethyan tropical-subtropical belt during the Cretaceous. This group of thermocline dwellers (intermediate) thrived during relatively cool climates and a wellstratified water column. But their temperature tolerance limit is relatively low and they are prone to extinctions when temperatures are either too cool or too warm [2].

[7] showed that planktonic foraminiferal diversity (number of species in entire sample) is greater in tropical areas than boreal areas. [7] and [26] noted that since planktonic foraminifera float at different water depths, their diversity increase from shallower to deeper water across shelf areas.

[68] proposed that the dominance of heterohelicids, rugoglobigerinids and globigerinelloids participant long ranging globotruncanids indicate the cool water. However, the increase in the abundance of double-keeled globotruncanids and many species (e.g., *Rugoglobigerina pennyi* and *R. milamensis*) indicative of warmer water conditions, represent the warmer climate.

Campanian Climate

In Jorband, increasing of CaCO3 deposition rate and whole specimens of planktonic foraminifera shows decreasing of dissolution of CaCO3 during the Campanian and at this time CCD was close to the warm water surface. In this case, no significant dissolution is evident in foraminiferal tests and calcite productivity should be significant factor.

However, in generally, planktonic foraminifera were diverse and abundant in samples from the Lower Jorband section, but the genus Globotruncana is the most distinctive and abundant. The globigeriniform tests were almost absent for this part of section except for Archaeoglobigerina species and Hedbergella holmdelensis. The Globigerinelloides ultramicra was common. Because keeled planktonic foraminifera have been shown to float deeper [25], [26], [31] and in today's oceans are restricted to warm temperature and tropical regions, their presence may indicate deeper and/or warmer waters during the deposition of the sediments compared to sediments of the upper Jorband successions.

Latest Campanian-Early Maastrichtian Climate

Many scientists have accepted that before Campanian- Maastrichtian boundary, the long- term Campanian global warming trend replaced by rapid cooling exactly in C-M boundary [68], [10], [38], [3], [5].

In this study in the latest Campanian and early Maastrichtian, the planktonic foraminiferal assemblage, consisting of long-ranging globotruncanids with *Heterohelix, Globigerinelloides, Archaeoglobigerina* and *Rugoglobigerina* which have been used as indicators of cooler conditions [59], [60], [61], [49], [32], [68], suggests that cooler water temperatures prevailed during this period. It is also implied by the sudden drop in the percentage abundance of the globotruncanids and the marked increase in the heterohelicids populations associated with presence of

Pseudotextularia and *Planoglobulina* species that lived in subsurface mixed layer. As some reports [29], [30], [46], [38] proposed that major sea-level regression coincided with the major cooling phases at 71.2-69.2 Ma and 67.3- 66.5 Ma, with due attention to decrease or disappear of marker deep dwellers and increasing of surface and subsurface planktonic foraminifera we suggest a regression in this period in Jorband area.

Maastrichtian Climate

Some records show that the Maastrichtian global climate was significantly cooler than during the overall late Cretaceous [57,24,15,8,9,68,42,44,38,39,3,4].

The dominance of heterohelicids, rugoglobigerinids and globigerinelloids continues into this part of the succession in Jorband section, indicating that cooler conditions still prevailed. This relatively cool period was interrupted by a short-term warming towards the top of the Maastrichtian where the *Rugoglobigerina pennyi* and *R. milamensis* increased and dominated (Fig. 4), which imply the existence of rather warmer conditions that probably resulted from oceanic circulation patterns and gyre configurations, which brought warmer waters [68] or a concomitant shift in water mass boundaries [32].

Towards the late Maastrichtian, in general, the heterohelicids and rugoglobigerinids are still the most dominating faunal group, while the globigerinelloids remain low in number. Double-keeled globotruncanids become distinctly abundant, however single-keeled planktonic forms are present but rare. The increase in the abundance of double-keeled globotruncanids suggests that the prevailing warmer conditions witch commenced at the base of CF6 continued into late Maastrichtian. In addition, the presence and increase in dwellers abundance of deeper the such as Abathomphalus mayaroensis, Gansserina gansseri, Globotruncanella havanensis, Gublerina cuvillieri and Laeviheterohelix glabrans in CF4 suggest upper sea levels or deeper basin during the late Maastrichtian.

Results and Discussion

In this study 60 species of Campanian-Maastrichtian planktonic foraminifera were identified.

The index planktonic foraminifera marked 10 biozones along the Jorband section that contains: *Racemiguembelina fructocosa* Zone (CF4), (late Maastrichtian), *Planoglobulina brazoensis* Zone (CF5), *Contusotruncana contusa* Zone (CF6) and *Gansserina gansseri* Zone (CF7) (early Maastrichtian), *Planoglobulina carseyae* Zone (CF8b) (earliest

Maastrichtian), *Globotruncana aegyptiaca* Zone (CF8a) (latest Campanian), *Globotruncanella havanensis* Zone (CF9) and *Radotruncana calcarata* Zone (CF10) (late Campanian), *Globotruncana ventricosa* Zone (middle Campanian) and *Globotruncanita elevata* Zone (early Campanian).

Biozonation used in this study is similar to the [44], [45], except *Pseudotextularia intermedia* (CF5), *Rugoglobigeria hexacamerata* (CF8b), and *Globigerinelloides* (*Globotruncanella*) subcarinatus (CF9) zones are replaced here by *Planoglobulina brazoensis*, *Planoglobulina carseyae* and *Globotruncanella havanensis* zones respectively and similar to [18] planktonic foraminifera biozonation for earlymiddle Campanian which could be correlating by tropical and sub tropical biozones.

In this study we placed the early-late Maastrichtian boundary at the first appearance of *R. fructicosa* following [2], [4], [50], [45], [46].

In spite of simultaneous of introduced biozones with [44], [45] and because of diachronous appearance of *R*. *hexacamerata* [44], [45] that first appears in *G*. *havanensis* biozone in this study we placed the FA of *P*. *carseyae* for Campanian-Maastrichtian boundary.

In Jorband section, the sedimentation was in a deep and warm open marine environment through the Campanian.

Before Campanian-Maastrichtian boundary, the longterm Campanian global warming trend replaced by rapid cooling exactly in C-M boundary in Latest Campanian.

Because of increase in shallower depth indicators in C-M boundary such as heterohelicids populations associated with presence of *Pseudotextularia* and *Planoglobulina* species that lived in subsurface mixed layer and the sudden drop in the percentage abundance of the globotruncanids, we estimate a regression in this period of time in Jorband section

The dominance of heterohelicids, rugoglobigerinids and globigerinelloids continues into Maastrichtian in Jorband section, indicating that cooler conditions still prevailed.

This relatively cool period was interrupted by a short-term warming towards the top of the Maastrichtian where the *Rugoglobigerina pennyi* and *R. milamensis* increased and dominated, which imply the existence of rather warmer condition.

Toward the late Maastrichtian, the presence and increase in the abundance of deeper dwellers such as *Abathomphalus mayaroensis, Gansserina gansseri, Globotruncanella havanensis, Gublerina cuvillieri* and *Laeviheterohelix glabrans* shows in the late Maastrichtian the basin was going deeper.



Figure 4. Relative abundances of planktonic foraminifera at Jorband section.



Plate 1.

- 1. Contusotruncana walfischensis (Todd), 1970; Lateral view, (Placed in zone CF7, Scale bar = 200µm)
- 2. Contusotruncana walfischensis (Todd), 1970; Spiral view, (Placed in zone CF7, Scale bar = 200µm)
- 3. Contusotruncana walfischensis (Todd), 1970; Umbilical view, (Placed in zone CF7, Scale bar = 200µm)
- 4. *Globotruncanita stuarti* (De Lapparent), 1918; Lateral view, (Placed in zone CF10, Scale bar = 100µm)
- 5. *Globotruncanita stuarti* (De Lapparent), 1918; Spiral view, (Placed in zone CF10, Scale bar = 200µm)
- 6. Globotruncanita stuarti (De Lapparent), 1918; Umbilical view, (Placed in zone CF10, Scale bar = 200µm)
- 7. *Globotruncanita stuartiformis* (Dalbiez), 1955; Lateral view, (Placed in zone CF10, Scale bar = 100µm)
- 8. Globotruncanita stuartiformis (Dalbiez), 1955; Spiral view, (Placed in zone CF10, Scale bar = 200µm)
- 9. Globotruncanita stuartiformis (Dalbiez), 1955; Umbilical view, (Placed in zone CF10, Scale bar = 200µm)
- 10. *Globotruncanita elevata* (Brotzen), 1934; Lateral view, (Placed in zone CF8a, Scale bar = 200µm)
- 11. *Globotruncanita elevata* (Brotzen), 1934; Spiral view, (Placed in zone CF8a, Scale bar = 200µm)
- 12. Globotruncanita elevata (Brotzen), 1934; Umbilical view, (Placed in zone CF8a, Scale bar = 200µm)
- 13. Gansserina gansseri (Bolli), 1951; Lateral view, (Placed in zone CF7, Scale bar = 100µm)
- 14. Gansserina gansseri (Bolli), 1951; Spiral view, (Placed in zone CF7, Scale bar = 100µm)
- 15. Gansserina gansseri (Bolli), 1951; Umbilical view, (Placed in zone CF7, Scale bar = 100μm)
- 16. Globotruncanella havanensis (Voorwijk), 1937; Lateral view, (Placed in zone CF9, Scale bar = 100µm)
- 17. Globotruncanella havanensis (Voorwijk), 1937; Spiral view, (Placed in zone CF9, Scale bar = 100µm)
- 18. Globotruncanella havanensis (Voorwijk), 1937; Umbilical view, (Placed in zone CF9, Scale bar = 100µm)
- 19. Globigerinelloides subcarinatus (Brönnimann), 1952; Lateral view, (Placed in zone CF6, Scale bar = 100µm)
- 20. *Globigerinelloides subcarinatus* (Brönnimann), 1952; Side view, (Placed in zone CF6, Scale bar = 100µm)



Plate 2.

- 1. Archaeoglobigerina cretacea (d'Orbigny), 1840; Lateral view, (Placed in zone CF7, Scale bar = 200µm)
- 2. Archaeoglobigerina cretacea (d'Orbigny), 1840; Spiral view, (Placed in zone CF7, Scale bar = 200µm)
- 3. Archaeoglobigerina blowi Pessagno, 1967; Lateral view, (Placed in zone CF7, Scale bar = $100 \mu m$)
- 4. Archaeoglobigerina blowi Pessagno, 1967; Spiral view, (Placed in zone CF7, Scale bar = 100µm)
- 5. Rugoglobigerina macrocephala, Brönnimann, 1952; Lateral view, (Placed in zone CF8a, Scale bar = 100µm)
- 6. Rugoglobigerina macrocephala, Brönnimann, 1952; Spiral view, (Placed in zone CF8a, Scale bar = 100µm)
- 7. Rugoglobigerina macrocephala, Brönnimann, 1952; Umbilical view, (Placed in zone CF8a, Scale bar = 100µm)
- 8. *Rugoglobigerina rugosa*, (Plummer), 1926; Lateral view, (Placed in zone CF8a, Scale bar = 100μm)
- 9. Rugoglobigerina rugosa, (Plummer), 1926; Spiral view, (Placed in zone CF8a, Scale bar = 100µm)
- 10. Rugoglobigerina rugosa, (Plummer), 1926; Umbilical view, (Placed in zone CF8a, Scale bar = 100µm)
- 11. Rugoglobigerina milamensis, Smith & Pessagno, 1973; Lateral view, (Placed in zone CF8a, Scale bar = 100µm)
- 12. Rugoglobigerina milamensis, Smith & Pessagno, 1973; Spiral view, (Placed in zone CF8a, Scale bar = 100µm)
- 13. Rugoglobigerina rotundata, Brönnimann, 1952; Lateral view, (Placed in zone CF8a, Scale bar = 100µm)
- 14. *Rugoglobigerina pennyi*, Brönnimann, 1952; Lateral view, (Placed in zone CF8a, Scale bar = 100µm)
- 15. Rugoglobigerina pennvi, Brönnimann, 1952; Spiral view, (Placed in zone CF8a, Scale bar = $100 \mu m$)
- 16. Rugoglobigerina pennyi, Brönnimann, 1952; Umbilical view, (Placed in zone CF8a, Scale bar = 100µm)
- 17. Rugoglobigerina hexacamerata Brönnimann, 1952; Lateral view, (Placed in zone CF8a, Scale bar = 100μm)
- 18. Rugoglobigerina hexacamerata Brönnimann, 1952; Spiral view, (Placed in zone CF8a, Scale bar = 100µm)
- 19. Rugoglobigerina hexacamerata Brönnimann, 1952; Umbilical view, (Placed in zone CF8a, Scale bar = 100µm)



Plate 3.

- 1. Contusotruncana fornicata (Plummer), 1931; Lateral view, (Placed in zone CF4, Scale bar = 100µm)
- 2. Contusotruncana fornicata (Plummer), 1931; Spiral view, (Placed in zone CF4, Scale bar = 100µm)
- 3. *Contusotruncana fornicata* (Plummer), 1931; Umbilical view, (Placed in zone CF4, Scale bar = 100µm)
- 4. Globotruncana linneiana D'Orbigny, 1839; Lateral view, (Placed in G. ventricosa zone, Scale bar = 100μm)
- 5. *Globotruncana linneiana* D'Orbigny , 1839; Spiral view, (Placed in *G. ventricosa* zone, Scale bar = $200 \mu m$)
- 6. Globotruncana linneiana D'Orbigny, 1839; Umbilical view, (Placed in G. ventricosa zone, Scale bar = 100μm)
- 7. Globotruncanita subspinosa (Pessagno), 1960; Lateral view, (Placed in zone CF8b, Scale bar = 100µm)
- 8. *Globotruncanita subspinosa* (Pessagno), 1960; Spiral view, (Placed in zone CF8b, Scale bar = 100μ m)
- 9. *Globotruncanita subspinosa* (Pessagno), 1960; Umbilical view, (Placed in zone CF8b, Scale bar = $100 \mu m$)
- 10. *Globotruncana arca* Cushman, 1926; Lateral view, (Placed in zone CF5, Scale bar = $100 \mu m$)
- 11. *Globotruncana arca* Cushman, 1926; Spiral view, (Placed in zone CF5, Scale bar = 100μ m)
- 12. *Globotruncana arca* Cushman, 1926; Spiral view, (Placed in zone CF5, Scale bar = 100μ m)
- 12. Group uncura area cusinian, 1720, spirar view, (raced in 2016 CF3, scale $0ar = 100 \mu m$)
- 13. *Globotruncanita angulata* (Tilev), 1951; Lateral view, (Placed in zone CF7, Scale bar = 100μ m)
- 14. *Globotruncanita angulata* (Tilev), 1951; Spiral view, (Placed in zone CF7, Scale bar = 100μm) 15. *Globotruncanita angulata* (Tilev), 1951; Spiral view, (Placed in zone CF7, Scale bar = 100μm)
- 16. *Globotruncanita angulata* (Tilev), 1951; lateral view, (Placed in zone CF7, Scale bar = 100μ m)
- 17. *Gublerina cuvilleri* Kikoine, 1948; Side view, (Placed in zone CF8a, Scale bar = $200 \mu m$)
- 18. *Gublerina cuvilleri* Kikoine, 1948; Side view, (Placed in zone CF8a, Scale bar = 200μ m)
- 19. Gublerina acuta De Klasz, 1953; Side view, (Placed in zone CF8a, Scale bar = 200µm)



Plate 4.

- 1. Abathomphalus mayaroensis (Bolli), 1951; Lateral view, (Placed in zone CF4, Scale bar = 200µm)
- 2. Abathomphalus mayaroensis (Bolli), 1951; Spiral view, (Placed in zone CF4, Scale bar = 200µm)
- 3. *Globotruncanita conica* (White), 1928; Lateral view, (Placed in zone CF4, Scale bar = 200µm)
- 4. *Globotruncana aegyptiaca* Nakkady, 1950; Spiral view, (Placed in zone CF8b, Scale bar = 100µm)
- 5. Globotruncana ventricosa White, 1928; Lateral view, (Placed in G. ventricosa zone, Scale bar = 100µm)
- 6. *Globotruncana ventricosa* White, 1928; Spiral view, (Placed in *G. ventricosa* zone, Scale bar = 200μ m)
- 7. Globotruncana ventricosa White, 1928; Umbilical view, (Placed in G. ventricosa zone, Scale bar = 200µm)
- 8. *Radotruncana calcarata* (Cushman), 1926; Spiral view, (Placed in zone CF10, Scale bar = 100µm)
- 9. Gansserina weidenmayeri (Gandolfi), 1955; Lateral view, (Placed in zone CF7, Scale bar = 100µm)
- 10. Gansserina weidenmayeri (Gandolfi), 1955; Umbilical view, (Placed in zone CF7, Scale bar = 100µm)
- 11. Contusotruncana contusa (Cushman), 1926; Lateral view, (Placed in zone CF6, Scale bar = 100µm)
- 12. Contusotruncana contusa (Cushman), 1926; Spiral view, (Placed in zone CF6, Scale bar = 100μm)
- 13. *Globotruncana falsostuarti*, (Sigal), 1952; Spiral view, (Placed in zone CF6, Scale bar = 200μm)
- 14. Globotruncana falsostuarti, (Sigal), 1952; lateral view, (Placed in zone CF6, Scale bar = 200µm)
- 15. Globotruncana lapparenti Brotzen 1936; Lateral view, (Placed in zone CF7, Scale bar = 200µm)
- 16. *Globotruncana lapparenti* Brotzen 1936; Spiral view, (Placed in zone CF7, Scale bar = 200µm)
- 17. Globotruncana lapparenti Brotzen 1936; Umbilical view, (Placed in zone CF7, Scale bar = 200µm)
- 18. Globotruncanella petaloida (Gandolfi), 1955; Lateral view, (Placed in zone CF8a, Scale bar = 100µm)
- 19. Globotruncanella petaloida (Gandolfi), 1955; Spiral view, (Placed in zone CF8a, Scale bar = 100µm)
- 20. Globotruncanella petaloida (Gandolfi), 1955; Umbilical view, (Placed in zone CF8a, Scale bar = 100µm)



Plate 5.

- 1. Racemiguembelina powelli Smith & Pessagno, 1973; Side view, (Placed in zone CF4, Scale bar = 200µm)
- 2. Racemiguembelina fructicosa Egger, 1899; Side view, (Placed in zone CF4, Scale bar = 100µm)
- 3. Pseudotextularia elegans (Rzehak), 1895; Edge view, (Placed in zone CF6, Scale bar = 100µm)
- 4. *Pseudotextularia elegans* (Rzehak), 1895; Side view, (Placed in zone CF6, Scale bar = 100µm)
- 5. Pseudoguembelina costulata (Cushman), 1938; Side view, (Placed in zone CF10, Scale bar = 100µm)
- 6. *Heterohelix navarroensis* Loeblich, 1951; Side view, (Placed in zone CF10, Scale bar = 200μ m)
- 7. *Pseudotextularia intermedia* De Klasz, 1953; Side view, (Placed in zone CF9, Scale bar = 100μ m)
- 8. *Pseudotextularia intermedia* De Klasz, 1953; Edge view, (Placed in zone CF6, Scale bar = $100 \mu m$)
- 9. *Pseudotextularia nuttalli* (Vorwijk), 1937; Edge view, (Placed in zone CF9, Scale bar = 100µm)
- 10. *Pseudotextularia nuttalli* (Vorwijk), 1937; Side view, (Placed in zone CF9, Scale bar = 200μ m)
- 11. *Heterohelix globulosa* (Ehrenberg), 1840; Edge view, (Placed in zone CF7, Scale bar = 200μ m)
- 12. *Heterohelix globulosa* (Ehrenberg), 1840; Side view, (Placed in zone CF7, Scale bar = $100 \mu m$)
- 13. Ventilaberella eggeri (Cushman), 1928; Side view, (Placed in zone CF8a, Scale bar = 200µm)
- 14. Laeviheterohelix glabrans (Cushman), 1938; Side view, (Placed in zone CF8b, Scale bar = 200µm)
- 15. Planoglobolina acervulinoides (Egger), 1899; Side view, (Placed in zone CF8a, Scale bar = 200µm)
- 16. Planoglobolina brazoensis Martin, 1972; Edge view, (Placed in zone CF8a, Scale bar = 200μm)
- 17. Planoglobolina brazoensis Martin, 1972; Side view, (Placed in zone CF8b, Scale bar = 200µm)
- 18. *Planoglobolina carseyae* (Plummer), 1931; Side view, (Placed in zone CF8b, Scale bar = 200µm)
- 19. Planoglobolina riograndensis (Martin), 1972; Side view, (Placed in zone CF8a, Scale bar = 200µm)

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