Nannostratigraphy and paleoenvironmental study of the lower boundary of the Kalat Formation in East and West of Kopeh- Dagh, Northeast Iran

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Abstract

This study presents the nannostratigraphy and nannofossil events in the lower boundary of Kalat Formation in the East and West of the Kopeh- Dagh basin. The Kalat Formation comprises of coarse grained detritus limestone with subordinate sandstone intercalations. In the current study, six sections have been chosen in the East and West of the basin which are as follow: Dobaradar section, Kalat section, Chahchaheh section, Sheikh section, Qaleh Zoo section and Jozak section. In the Dobaradar section 22 species have been determined, in the Kalat section 25 species, in the Chahchaheh section 32 species, in the Sheikh section 28 species, in the Qaleh Zoo section 20 species, and in the Jozak section 18 species have been determined. The boistratigraphy based on calcareous nannofossils allows the identification of nannofossil standard zones CC25- CC26 in the East, and CC21 and CC26 in the West of the Kopeh- Dagh Basin in all of the sections, indicating that the investigated deposits are Late Maastrichtian – late Late Maastrichtian in age in all sections in the East, and early Late Campanian – late Late Maastrichtian in all sections in the West of the Kopeh- Dagh Basin. The nannofossils response to the Maastrichtian climate evolution is investigated in the lower boundary of Kalat Formation. Warm water indicators (Uniplanarius sissinghii, Micula murus and Micula prinsii) suggest warm surface water conditions in the studied thickness. In the lower boundary of the Kalat Formation, based on Lithraphidites spp. and Watznaueria barnesae, lower fertility conditions with low productivity at the end of the Maastrichtian were suggested.

Keywords: *Kalat, Kopeh- Dagh, Iran, Nannostratigraphy, Paleoenvironment*

Introduction

A detailed study of calcareous nannofossils using an optical microscope was performed. In this study, the investigation of calcareous nannofossil assemblages from the aforementioned boundary allowed the testing of nannofossil biozonation schemes, which in turn will be used to document the paleoecological changes throughout the latest Cretaceous of the Kopeh- Dagh basin. The calcareous nannofossils are preserved at the studied sections and include several species that have not been recorded previously.

The aim of this study is to: (1) determine the calcareous nannofossil assemblages, (2) discuss the possibility of applying the standard zonation, (3) assess paleoecological conditions of this area, and (4) demonstrate the stratigraphic continuity of sediments across this boundary in the east and west of the Kopeh- Dagh Basin.

Geological setting

The Kopeh- Dagh Basin has a Cretaceous sedimentary succession including marine shales, marls, marly limestones, and subordinate sandstones. This sequence seems to represent all stages of the Cretaceous period (Stocklin, 1968; Afshar Harb, 1969).

The Kalat formation is a unit of limestone existing in the central and eastern part of the Kopeh- Dagh Basin in Iran. The limestone contains subordinate sandstone intercalations and is conformably interbedded between the sandy Neyzar formation from below and the shaly Nafteh formation from above. In the western part of the Kopeh- Dagh Basin, equivalents of the Kalat Formation unconformably overlie marls and shales, which could be attributed to the Abderaz- Sanganeh formations. The Kalat formation is correlated with the Meaninsk Suite in Soviet Turkmenistan. Thickness of this formation decreases from the east to west of the Kopeh- Dagh Basin (Stocklin, 1971).

In the present study, samples were taken from the uppermost part of the Neyzar formation and the lowermost part of the Kalat formation in the east (the boundary between Neyzar and Kalat formations) and from the upper part of the Abderaz formation and the lower part of the Kalat formation in the western part of the Kopeh- Dagh Basin (the boundary between Abderaz and Kalat formations). The sampling was done within a thickness of 30 meters and contained the sandstone and sandy limestone in the east; limestone and sandy limestone in the west (Figures 2, 3). The studied sections are named Dobaradar, Kalat, and Chahchaheh in the east, and Sheikh, Qaleh Zoo, and Jozak in the west (Figure 1).

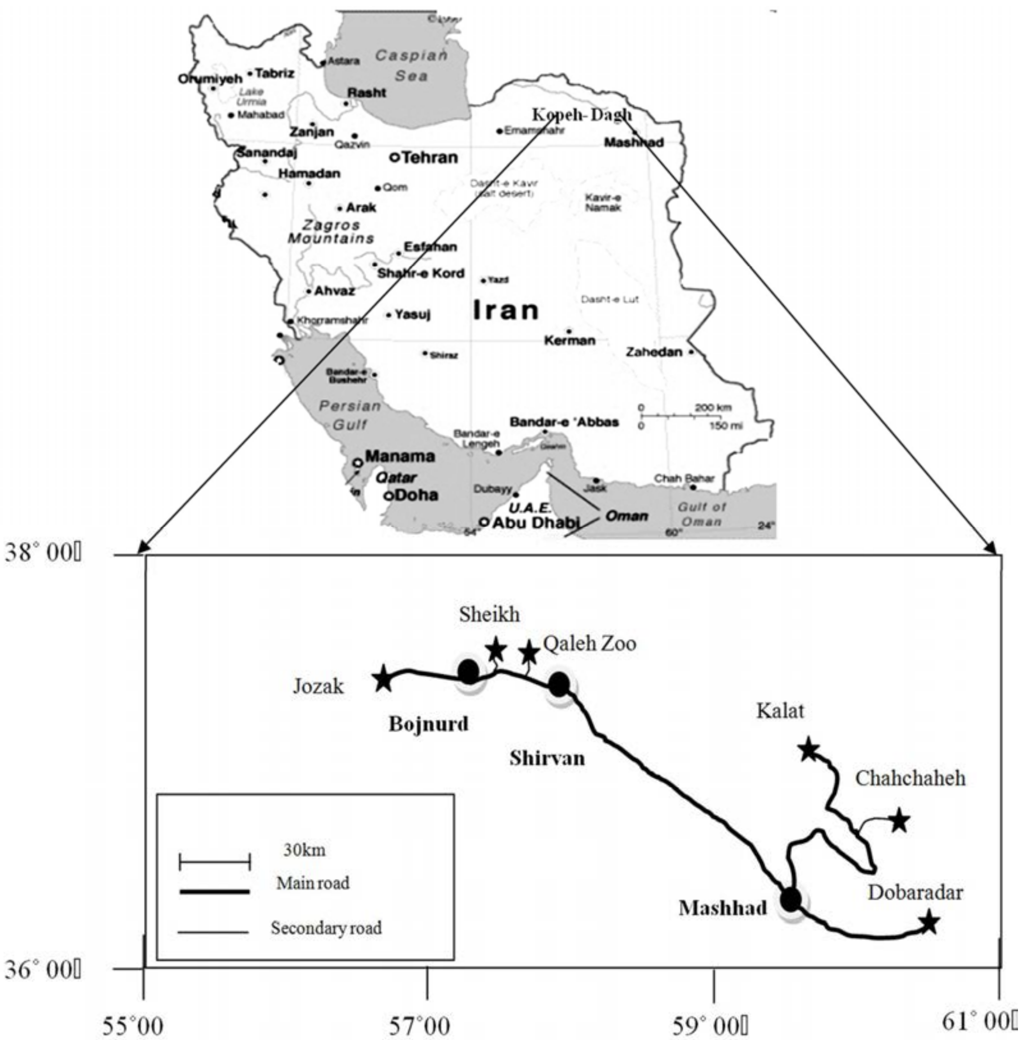


Figure 1: location of the studied sections in the east and the west of the Kopeh- Dagh Basin in Iran.

Samples and Methods

A total of 10 samples of the lower boundary of the Kalat formation in the east and 15 samples in the west of the Kopeh- Dagh Basin were collected. Nannofossils were prepared using the smear- slide method, in linne with the standard procedures (Bown & Young, 1998), and the examination of nannofloras was performed by using an Olympus polarizing microscope; BH2 model at 1250x magnification. The images were captured with a digital camera. All images were taken in either cross- polarized light (XPL) or (PPL) (Figures 7-11).

All calcareous nannofossil specimens were identified by using the taxonomic schemes of Thierstein, 1976 ; Perch- Nielsen, 1985; Burnett, 1998, Cepek and Hay, 1969; Young, 1999.

For the purpose of paleoecological studies and because of low abundance of nannofossils in the lower boundary of the Kalat Formation, all nannofossil species were counted in twenty purviews (The number of species is different in each slide, but the maximum number of species is 80). Then the percentages of each species for drawing the diagrams were calculated (Tables1-6).

Previous Investigations

The earliest paleontological studies of the Cretaceous formations of the Kopeh- Dagh Basin in Iran, and particularly of the Kalat formation, have been done based on the foraminifera e.g., Afshar Harb, 1979.

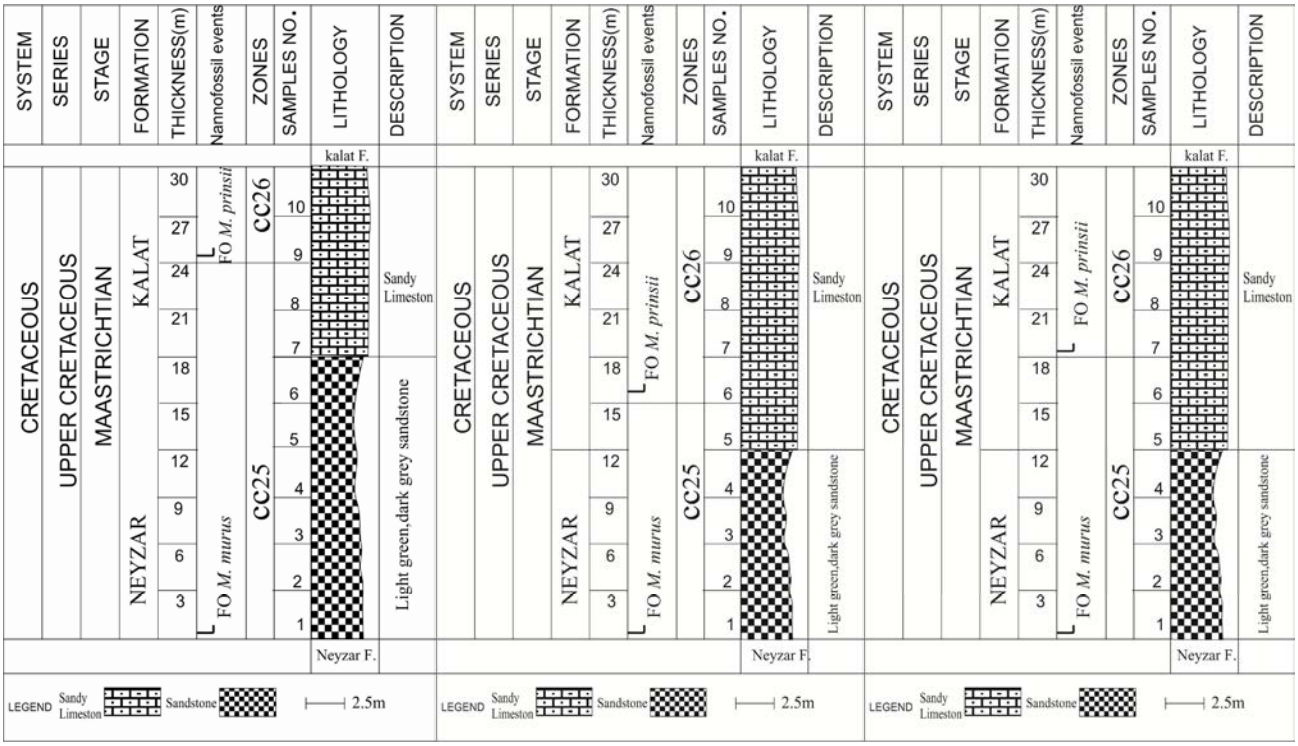


Figure 2: a: Lithostratigraphic column of the boundary between Neyzar and Kalat formations in Dobaradar section b: Lithostratigraphic column of the boundary between Neyzar and Kalat formations in Chahchaheh section c: Lithostratigraphic column of the boundary between Neyzar and Kalat formations in Kalat section

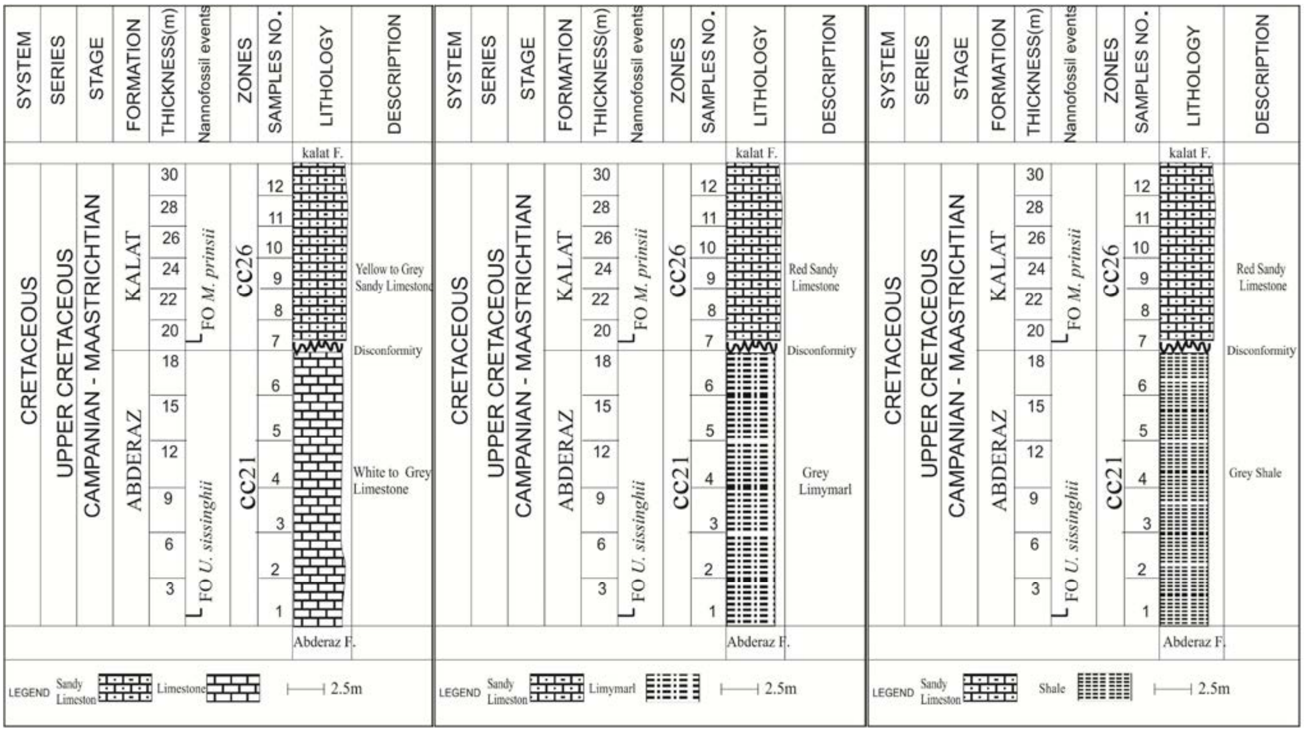


Figure 3: a: Lithostratigraphic column of the boundary between Neyzar and Kalat formations in Jozak section b: Lithostratigraphic column of the boundary between Neyzar and Kalat formations in Qaleh Zoo section c: Lithostratigraphic column of the boundary between Neyzar and Kalat formations in Sheikh section

Table 1: Abundance chart of the identified calcareous nannofossils species in samples from the upper part of Neyzar Formation and the lower part of Kalat Formation in the Dobaradar section.

MAASTRICHTIAN										AGE
NEYZAR					KALAT					FORMATION
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	SAMPLE No.
0.00	2.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	*Acuturris scotus*
0.00	0.00	1.00	0.00	2.00	0.00	1.00	1.00	1.00	0.00	*Arkhangelskiella cymbiformis*
1.00	0.00	1.00	0.00	0.00	2.00	0.00	1.00	0.00	0.00	*Arkhangelskiella specillata*
0.00	0.00	2.00	1.00	0.00	0.00	1.00	0.00	1.00	1.00	*Braarudosphaera bigelowii*
1.00	1.00	1.00	0.00	2.00	1.00	0.00	1.00	0.00	0.00	*Calcicalathina alta*
9.00	8.00	10.00	8.00	6.00	4.00	5.00	4.00	3.00	3.00	*Calculites obscurus*
0.00	1.00	0.00	0.00	2.00	0.00	0.00	1.00	0.00	1.00	*Ceratolithoides aculeus*
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	*Ceratolithoides kamptneri*
0.00	1.00	0.00	0.00	0.00	1.00	0.00	2.00	0.00	0.00	*Cribrosphaerella ehrenbergii*
1.00	0.00	0.00	1.00	0.00	2.00	2.00	0.00	1.00	0.00	*Eiffellithus gorkae*
1.00	0.00	1.00	1.00	0.00	0.00	0.00	1.00	0.00	0.00	*Eiffellithus turriseffelii*
0.00	1.00	0.00	2.00	0.00	0.00	2.00	2.00	0.00	1.00	*Lithraphidites carniolensis*
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	*Lithraphidites quadratus*
13.00	11.00	10.00	11.00	9.00	8.00	6.00	5.00	6.00	4.00	*Lucianorhabdus cayeuxii*
1.00	1.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00	0.00	*Microrhabdulus decoratus*
0.00	1.00	0.00	0.00	1.00	0.00	0.00	1.00	1.00	0.00	*Micula concava*
17.00	19.00	22.00	21.00	24.00	25.00	27.00	26.00	29.00	31.00	*Micula decussata*
1.00	0.00	0.00	2.00	0.00	1.00	0.00	1.00	2.00	0.00	***Micula murus***
0.00	1.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	*Micula premurus*
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	2.00	***Micula prinsii***
1.00	0.00	0.00	1.00	1.00	0.00	2.00	0.00	0.00	1.00	*Micula swastika*
14.00	13.00	11.00	12.00	10.00	8.00	7.00	9.00	7.00	6.00	*Watznaueria barnesae*
A. cymbiformis								***N. frequens***		**BIOZONES**
CC25								CC26		**NANNOFOSSIL ZONE** (Sissingh 1977)

The large scale studies of the upper Cretaceous calcareous nannofossils have been carried out mostly in the Kopeh- Dagh Basin in Iran by Hadavi e.g., Hadavi (2007), Hadavi and Musazaddeh (2006), Hadavi and Notghi Moghaddam (2010) and Hadavi (2004) (nannofossils studies of the Aitamir, Abderaz, and Abtalkh formations). However, the nannofossil studies of the Kalat formation were carried out by Hadavi and Moheghy (2009) and Hadavi and Amel (2004).

The previous studies focused on the entire formation, especially the investigation of biostratigraphy. However, in the present study, biostratigraphy and paleoecology of the lower boundary of the Kalat formation (between Neyzar and Kalat formations in the east and between the Abderaz and Kalat formations in the west of the Kopeh- Dagh Basin) were examined.

Results

Calcareous Nannofossil Preservation

In the studied samples, all specimens in the east were well preserved, whereas species in the west were either well or moderately preserved, showing a slight degree of etching and overgrowth.

In the Maastrichtian, *Micula decussate* is the taxon with the most resistance to dissolution; *M. murus* has a much lower ratio of resistance to dissolution; and *W. barnesae* is absolutely solution-resistant (Thierstein, 1980). The abundance of *W. barnesae* shows a strong decrease in the interval where *Micula decussata* peaks; therefore, diagenetic processes cannot explain the high abundance of *M. decussata* and the other changes observed in the nannofossil assemblage. Patterns of abundances as well as diversity indices can be interpreted as a reflection of original paleoecological conditions.

In the present samples, structures of the central area of hetercoccoliths were identified; therefore, diagenetic processes did not profoundly alter the original nannofossil assemblages in this boundary.

Nannofossil Diversity and Abundance

In the studied sections, 22 species of calcareous nannofossils in the Dobaradar section, 25 species in the Kalat section, 32 species in the Chahchaheh section, 28 species in the Sheikh section, 20 species in the Qaleh Zoo section, and 18 species in the Jozak section were identified from the lower boundary of the Kalat formation (Tables1-6). In the boundary between Neyzar and Kalat formations in the east of the Kopeh- Dagh Basin, diversity tends to increase toward higher sections (Figure 4a), whereas in the boundary between Abderaz and Kalat formations in the west of the Kopeh- Dagh Basin, diversity tends to decrease toward higher sections (Figure 4b). In the east and west of the Kopeh- Dagh Basin, the abundance of samples varies; for example, *W. barnesae* toward higher sections decrease (Figure5), whereas *M. decussata* increases (Figure 6). Some species belonging to Zeugrhabdotus, Tranolithus, and Prediscosphaera existed only sporadically with relatively low percentages. In the studied sections, *Uniplanarius* spp. is the most abundant in the first samples, while *M. prinsii* is identified from only the uppermost part of these sections. Other taxa such as *Braarudosphaera* spp., *Calcicalathina alta, Acuturris scoutus, and Eiffellithus* spp. are present in the samples in much lower abundances.

Table 2: Abundance chart of the identified calcareous nannofossils species in samples from the upper part of Neyzar Formation and the lower part of Kalat Formation in the Chahchaheh section.

MAASTRICHTIAN										AGE
NEYZAR				KALAT						FORMATION
1	2	3	4	5	6	7	8	9	10	SAMPLE No.
0.00	0.00	1.00	1.00	0.00	0.00	2.00	0.00	1.00	1.00	*Acuturris scotus*
0.00	0.00	0.00	2.00	2.00	0.00	1.00	0.00	1.00	0.00	*Arkhangelskiella cymbiformis*
0.00	0.00	1.00	0.00	1.00	0.00	0.00	1.00	0.00	1.00	*Arkhangelskiella specillata*
2.00	0.00	0.00	1.00	0.00	0.00	1.00	1.00	0.00	3.00	*Braarudosphaera bigelowii*
0.00	1.00	2.00	0.00	1.00	2.00	1.00	0.00	1.00	0.00	*Calcicalathina alta*
12.00	11.00	12.00	11.00	10.00	9.00	8.00	6.00	7.00	4.00	*Calculites obscurus*
0.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	*Ceratolithoides aculeus*
0.00	0.00	0.00	0.00	0.00	1.00	2.00	0.00	0.00	1.00	*Ceratolithoides kamptneri*
0.00	0.00	1.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	*Ceratolithoides self- trailiae*
0.00	0.00	1.00	0.00	0.00	2.00	0.00	0.00	0.00	1.00	*Corollithion exigum*
0.00	1.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	*Corollithion signum*
1.00	1.00	0.00	0.00	1.00	0.00	0.00	2.00	0.00	1.00	*Cribrosphaerella ehrenbergii*
0.00	0.00	0.00	1.00	0.00	0.00	2.00	0.00	0.00	0.00	*Cylindralithus biarcus*
0.00	2.00	0.00	0.00	0.00	1.00	0.00	1.00	1.00	0.00	*Eiffellithus gorkae*
1.00	0.00	0.00	1.00	1.00	0.00	1.00	0.00	2.00	0.00	*Eiffellithus turriseffelii*
1.00	0.00	2.00	1.00	1.00	1.00	0.00	2.00	0.00	0.00	*Lithraphidites carniolensis*
0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	2.00	*Lithraphidites quadratus*
13.00	11.00	12.00	11.00	10.00	8.00	7.00	6.00	7.00	5.00	*Lucianorhabdus cayeuxii*
1.00	0.00	0.00	1.00	0.00	1.00	0.00	0.00	1.00	0.00	*Microrhabdulus belgicus*
3.00	0.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00	1.00	*Microrhabdulus decoratus*
0.00	0.00	1.00	1.00	2.00	0.00	1.00	0.00	1.00	0.00	*Micula concava*
19.00	21.00	23.00	26.00	27.00	29.00	31.00	30.00	33.00	34.00	*Micula decussata*
1.00	0.00	2.00	0.00	1.00	1.00	1.00	0.00	1.00	0.00	***Micula murus***
0.00	0.00	0.00	1.00	0.00	0.00	1.00	1.00	0.00	1.00	*Micula premurus*
0.00	0.00	0.00	0.00	0.00	1.00	0.00	2.00	0.00	1.00	***Micula prinsii***
1.00	1.00	0.00	0.00	0.00	1.00	0.00	1.00	2.00	0.00	*Micula swastika*
0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	2.00	0.00	*Prediscosphaera cretacea*
1.00	0.00	1.00	0.00	0.00	0.00	0.00	3.00	0.00	2.00	*Retecapsa angustiforata*
18.00	16.00	14.00	15.00	13.00	11.00	10.00	12.00	8.00	7.00	*Watznaueria barnesae*
0.00	0.00	2.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	*Zeugrhabdotus bicrescenticus*
0.00	1.00	0.00	0.00	2.00	0.00	0.00	0.00	1.00	1.00	*Zeugrhabdotus erectus*
0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	*Zeugrhabdotus noelia*
A. cymbiformis					***N. frequens***					**BIOZONES**
CC25					CC26					**NANNOFOSSIL ZONE** (Sissingh 1977)

Biostratigraphy and Zonation

The studied interval spans the calcareous nannofossil zones CC25- CC26 of Sissingh, 1977 in the east and CC21 and CC26 in the west of the Kopeh- Dagh Basin. They were modified and illustrated in Perch-Nielsen, 1985.

These biozones cover the Late Maastrichtian to late Late Maastrichtian in the east and early Late Campanian to late Late Maastrichtian in the west. The proposed biozones are arranged from base to the top and they are *Quadrum sissinghii* zone (CC21), *Arkhangelskiella cymbiformis* zone (CC25), and *Nephrolithus frequens* zone (CC26).

Quadrum Sissinghii Zone (CC21)

Sissingh proposed the Quadrum sissinghii zone, 1977. The age of this zone is early Late Campanian. The zone was explained as the interval from the first occurrence (FO) of *Q. sissinghii* to Fo *Quadrum trifidum* by Sissingh, 1977. This zone is identified in the upper part of the Abderaz formation in the Jozak, Qaleh Zoo, and Sheikh sections in the western part of the Kopeh- Dagh, and it is dominated, in addition to the marker species, by *Lucianorhabdus cayeuxii* – *Watznaueria barnesae* - *Watznaueria biporta* – *Micula decussata* - *Eiffellithus gorkae* -*Eiffellithus turriseiffelii*- *Quadrum gothicum*

Table 3: Abundance chart of the identified calcareous nannofossils species in samples from the upper part of Neyzar Formation and the lower part of Kalat Formation in the Kalat section.

MAASTRICHTIAN										AGE
NEYZAR				KALAT						FORMATION
1	2	3	4	5	6	7	8	9	10	SAMPLE No.
0.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	*Acuturris scotus*
0.00	0.00	1.00	0.00	3.00	0.00	2.00	0.00	1.00	1.00	*Arkhangelskiella cymbiformis*
0.00	3.00	0.00	0.00	0.00	1.00	0.00	0.00	2.00	0.00	*Arkhangelskiella specillata*
0.00	0.00	0.00	1.00	0.00	0.00	0.00	3.00	0.00	1.00	*Braarudosphaera bigelowii*
0.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00	*Calcicalathina alta*
10.00	9.00	11.00	12.00	10.00	8.00	7.00	6.00	4.00	4.00	*Calculites obscurus*
0.00	1.00	0.00	1.00	0.00	2.00	0.00	0.00	0.00	0.00	*Ceratolithoides aculeus*
0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	0.00	0.00	*Ceratolithoides kamptneri*
0.00	0.00	0.00	2.00	0.00	0.00	1.00	0.00	1.00	1.00	*Cribrosphaerella ehrenbergii*
0.00	0.00	0.00	2.00	0.00	0.00	1.00	0.00	1.00	0.00	*Corollithion signum*
0.00	0.00	1.00	1.00	0.00	0.00	2.00	0.00	1.00	0.00	*Eiffellithus gorkae*
0.00	0.00	0.00	2.00	0.00	1.00	0.00	0.00	0.00	0.00	*Eiffellithus turriseffelii*
0.00	1.00	0.00	0.00	2.00	0.00	0.00	1.00	1.00	0.00	*Lithraphidites carniolensis*
0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	*Lithraphidites quadratus*
11.00	10.00	8.00	9.00	8.00	7.00	6.00	5.00	6.00	4.00	*Lucianorhabdus cayeuxii*
0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00	2.00	*Microrhabdulus decoratus*
1.00	0.00	0.00	0.00	0.00	1.00	2.00	0.00	0.00	0.00	*Micula concava*
21.00	20.00	22.00	24.00	25.00	27.00	29.00	28.00	31.00	33.00	*Micula decussata*
1.00	1.00	0.00	0.00	2.00	1.00	1.00	0.00	1.00	0.00	***Micula murus***
0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	1.00	*Micula premurus*
0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	1.00	***Micula prinsii***
0.00	1.00	0.00	1.00	0.00	0.00	0.00	2.00	0.00	1.00	*Micula swastika*
16.00	15.00	17.00	16.00	14.00	13.00	11.00	12.00	9.00	8.00	*Watznaueria barnesae*
0.00	1.00	0.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	*Zeugrhabdotus bicrescenticus*
0.00	1.00	0.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	*Zeugrhabdotus erectus*
A. cymbiformis						***N. frequens***				**BIOZONES**
CC25						CC26				**NANNOFOSSIL ZONE** (Sissingh 1977)

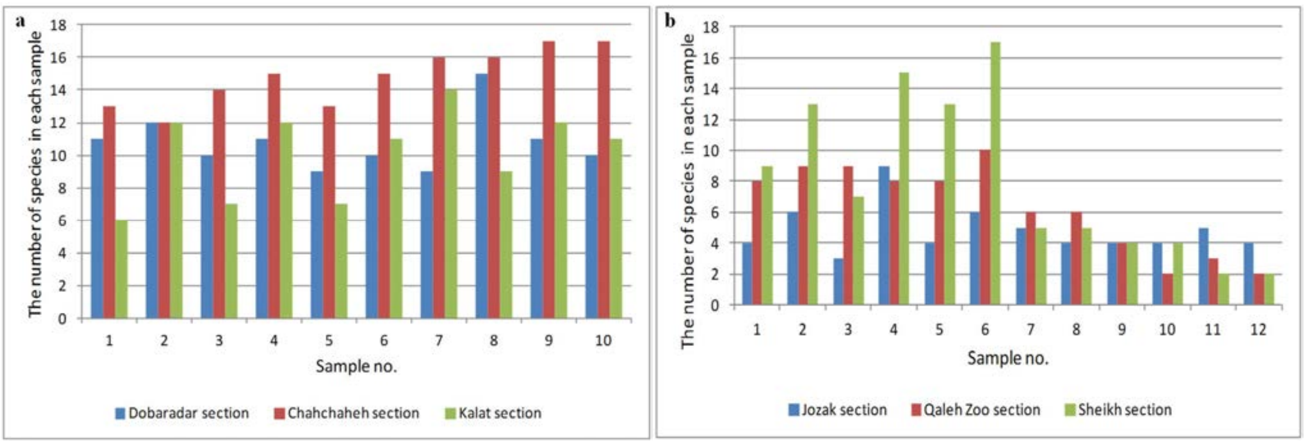


Figure 4: Vertical changes in the diversity of the identified calcareous nannofossils species in: a: The boundary between Neyzar and Kalat formations in the Dobaradar, Chahchaheh, and Kalat sections in the eastern part of the Kopeh- Dagh Basin b: The boundary between Abderaz and Kalat formations in the Jozak, Qaleh Zoo, and Sheikh sections in the western part of the Kopeh- Dagh Basin

Table 4: Abundance chart of the identified calcareous nannofossils species in samples from the upper part of Abderaz Formation and the lower part of Kalat Formation in the Jozak section.

CAMPANIAN						MASSTRICHTIAN						AGE
ABDERAZ						KALAT						FORMATION
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**SAMPLE No.**
0.00	1.00	0.00	8.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*Aspidolithus parcus expansus*
0.00	0.00	0.00	9.84	0.00	0.00	0.00	0.00	13.50	0.00	0.00	0.00	*Braarudosphaera bigelowii*
74.30	79.18	65.71	49.68	85.00	64.00	73.52	68.81	62.50	69.80	70.00	75.27	*Calcicalathina alta*
0.00	0.00	0.00	6.20	0.00	8.00	0.00	0.00	0.00	0.00	0.00	0.00	*Calculites obscurus*
0.00	0.00	0.00	6.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*Calculites ovalis*
0.00	0.00	0.00	6.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*Eiffellithus eximius*
0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.33	0.00	0.00	0.00	0.00	*Eiffellithus gorkae*
0.00	0.00	0.00	0.00	0.00	0.00	2.94	0.00	0.00	0.00	0.00	0.00	*Lucianorhabdus cayeuxii*
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.25	0.00	*Micula decussata*
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.50	0.00	0.00	4.00	*Micula murus*
0.00	0.00	0.00	0.00	0.00	0.00	8.82	6.20	0.00	8.47	8.03	7.03	***Micula prinsii***
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.34	0.00	0.00	*Micula swastica*
5.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*Nannoconus sp*
0.00	2.70	0.00	0.00	0.00	4.00	2.94	0.00	0.00	0.00	6.25	0.00	*Quadrum gothicum*
0.00	0.00	0.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*Tranolithus gabalus*
9.03	7.30	0.00	8.01	6.45	8.00	0.00	0.00	0.00	0.00	0.00	0.00	***Uniplanarius sissinghii***
11.78	8.33	11.50	17.39	9.47	9.70	5.57	5.71	2.70	3.84	3.00	2.00	*Watznaueria barnesae*
0.00	5.42	22.85	4.41	8.55	4.00	0.00	0.00	0.00	0.00	0.00	0.00	*Watznaueria biporta*
U. sissinghii						***N. frequence***						**BIOZONES**
CC21						**CC26**						**NANNOFOSSIL ZONE** (Sissingh1977)

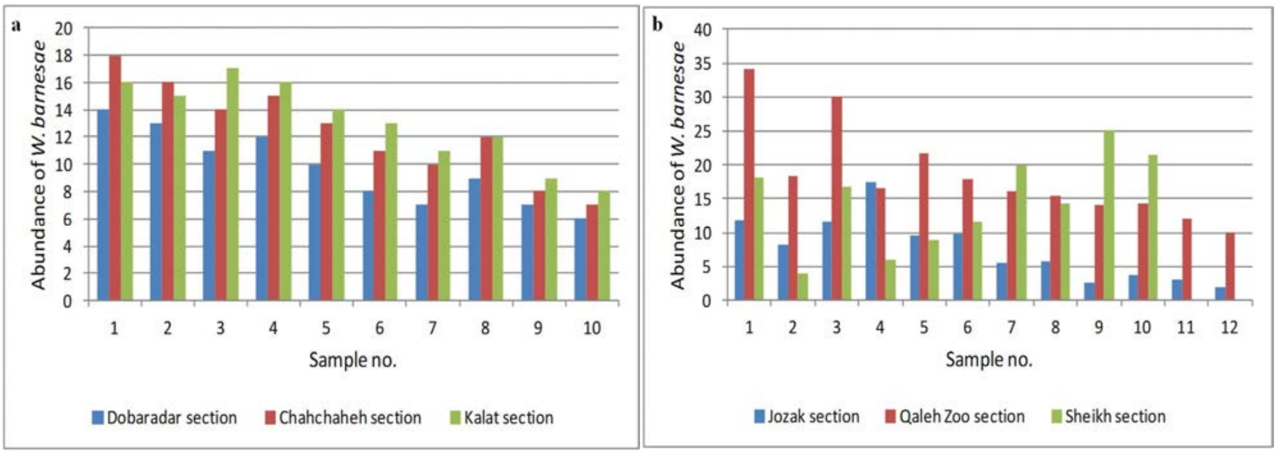


Figure 5: Vertical changes in the relative abundance of the *Watznaueria barnesae* in: a: The boundary between Neyzar and Kalat formations in the Dobaradar, Chahchaheh, and Kalat sections in the eastern part of the Kopeh- Dagh Basin b: The boundary between Abderaz and Kalat formations in the Jozak, Qaleh Zoo, and Sheikh sections in the western part of the Kopeh- Dagh Basin

Arkhangelskiella Cymbiformis Zone (CC25)

The *Arkhangelskiella cymbiformis* zone was proposed by Perch- Nielsen *et al.,* 1982, emended by Sissingh, 1977. The age of this zone is Late Maastrichtian. This zone is identified from the last occurrence (Lo) of *Reinhardtites levis* to Fo of *N. frequens*; however, the upper boundary of this zone in low latitudes is determined by the Fo of *M. murus.* The most dominant species in this zone, besides the marker species, are *L. cayeuxii - W. barnesae - Micula praemurus - M. decussata*

Nephrolithus Frequens Zone (CC26)

Cepek and Hay proposed this zone, 1969. The age of this zone is late Late Maastrichtian. It includes the interval from the Fo to the Lo of *N. frequens* in high latitudes. In low latitudes, the Fo of *M. murus* can be used to determine the lower boundary of this zone (Perch- Nielsen, 1985). The most dominant species in this zone, in addition to the marker species, are *L. cayeuxii*- *Lithraphidites carniolensis*- *Lithraphidites quadratus*- *M. murus*- *M. praemurus* - *M. decussata* - *W. barnesae*.

In the studied sections in the east of the Kopeh-Dagh Basin, on the basis of calcareous nannoplankton zones, CC25 continues from the uppermost part of the Neyzar formation to the lower part of the Kalat formation. Thus, a continuous sedimentary sequence across the boundary between the Neyzar and Kalat formations was suggested Whereas in the west, based on the lack of CC22- CC23- CC24 and CC25 zones between the uppermost part of the Abderaz formation and the lower part of the Kalat formation, a discontinuous sedimentary sequence across the boundary between the Abderaz and Kalat formations was suggested.

Table 5: Abundance chart of the identified calcareous nannofossils species in samples from the upper part of Abderaz Formation and the lower part of Kalat Formation in the Qaleh Zoo section.

CAMPANIAN						MASSTRICHTIAN						AGE
ABDERAZ						KALAT						FORMATION
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	SAMPLE No.
0.00	7.25	3.33	0.00	4.34	0.00	0.00	0.00	0.00	87.50	87.56	89.55	*Aspidolithus parcus constrictus*
0.00	5.00	3.33	0.00	0.00	0.00	9.00	0.00	0.00	0.00	0.00	0.00	*Braarudosphaera bigelowii*
0.00	21.05	0.00	32.34	17.30	21.42	36.36	66.61	85.57	0.00	0.00	0.00	*Calcicalathina alta*
4.54	2.63	3.33	0.00	4.34	7.14	9.00	0.00	0.00	0.00	0.00	0.00	*Calculites obscurus*
0.00	0.00	0.00	0.00	0.00	7.14	0.00	0.00	0.00	0.00	0.00	0.00	*Cyclagelosphaera reinhardtii*
9.09	0.00	3.33	5.00	4.34	7.14	0.00	0.00	0.00	0.00	0.00	0.00	*Eiffellithus eximius*
0.00	0.00	3.33	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*Eiffellithus gorkae*
4.54	2.63	0.00	5.00	4.34	7.14	0.00	0.00	0.00	0.00	0.00	0.00	*Eiffellithus turriseiffelii*
4.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*Lithraphidites carniolensis*
0.00	5.26	0.00	0.00	0.00	0.00	0.00	8.33	8.40	0.00	0.00	0.00	*Lucianorhabdus maleformis*
9.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*Micula decussata*
0.00	0.00	0.00	0.00	0.00	0.00	9.00	8.40	6.02	0.00	4.03	0.00	***Micula prinsii***
0.00	4.61	6.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*Micula swastica*
0.00	0.00	0.00	0.00	4.34	0.00	0.00	8.33	0.00	0.00	0.00	0.00	*Nannoconus kamptneri*
0.00	0.00	3.03	5.00	0.00	3.57	9.36	8.33	0.00	0.00	0.00	0.00	*Quadrum gothicum*
0.00	0.00	0.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*Tranolithus gabalus*
2.27	0.00	3.33	0.00	0.00	3.57	0.00	0.00	0.00	0.00	0.00	0.00	***Uniplanarius sissinghii***
34.09	18.42	30.00	16.66	21.70	17.85	16.00	15.33	14.00	14.33	12.00	10.00	*Watznaueria barnesae*
31.84	33.15	37.00	21.00	34.96	24.04	0.00	0.00	0.00	0.00	0.00	0.00	*Watznaueria biporta*
0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	*Zeugrhabdotus embergeri*
U. sissinghii						*N. frequence*						**BIOZONES**
CC21						CC26						**NANNOFOSSIL ZONE** (Sissingh1977)

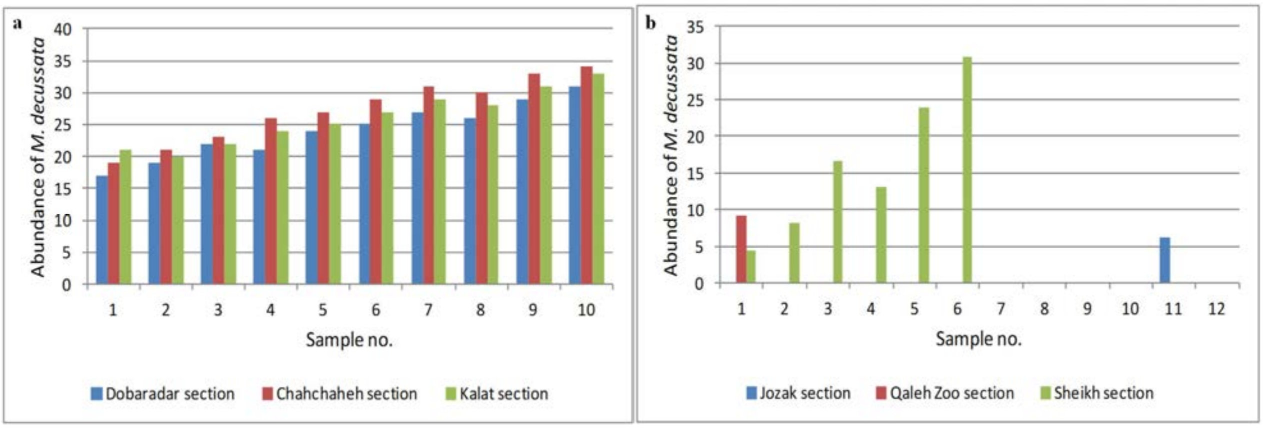


Figure 6: Vertical changes in the relative abundance of the *Micula decussata* in: a: The boundary between Neyzar and Kalat formations in the Dobaradar, Chahchaheh, and Kalat sections in the eastern part of the Kopeh- Dagh Basin b: The boundary between Abderaz and Kalat formations in the Jozak, Qaleh Zoo, and Sheikh sections in the western part of the Kopeh- Dagh Basin

Table 6: Abundance chart of the identified calcareous nannofossils species in samples from the upper part of Abderaz Formation and the lower part of Kalat Formation in the Sheikh section.

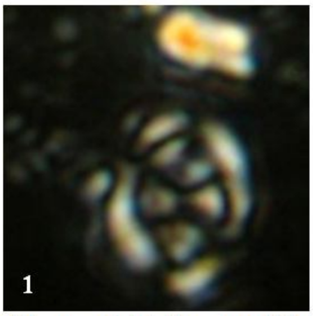
CAMPANIAN						MASSTRICHTIAN						AGE
ABDERAZ						KALAT						FORMATION
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**SAMPLE No.**
4.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*Acuturris scotus*
0.00	0.00	0.00	1.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*Arkhangelskiella specillata*
0.00	12.16	16.55	3.57	7.00	8.45	0.00	0.00	0.00	21.42	0.00	0.00	*Aspidolithus parcus constrictus*
0.00	0.00	0.00	0.00	1.00	0.76	0.00	0.00	0.00	0.00	0.00	0.00	*Aspidolithus parcus parcus*
0.00	1.35	0.00	0.00	1.00	0.00	6.66	0.00	0.00	0.00	0.00	0.00	*Braarudosphaera bigelowii*
0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.28	8.33	0.00	76.00	77.83	*Calcicalathina alta*
9.09	5.40	0.00	25.00	8.00	6.92	33.33	0.00	16.66	0.00	0.00	0.00	*Calculites obscurus*
0.00	0.00	0.00	3.57	0.00	2.30	0.00	0.00	0.00	0.00	0.00	0.00	*Calculites ovalis*
31.83	1.35	0.00	3.57	0.00	2.30	0.00	0.00	0.00	0.00	0.00	0.00	*Cyclagelosphaera reinhardtii*
4.54	16.21	16.70	0.00	12.00	2.30	6.66	14.28	0.00	7.14	0.00	0.00	*Eiffellithus eximius*
0.00	1.35	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*Eiffellithus gorkae*
0.00	4.05	0.00	2.38	2.00	4.61	0.00	0.00	0.00	0.00	0.00	0.00	*Eiffellithus turriseiffelii*
0.00	0.00	0.00	1.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*Eprolithus floralis*
0.00	0.00	0.00	0.00	0.00	1.53	0.00	0.00	0.00	0.00	0.00	0.00	*Lucianorhabdus arcuatus*
0.00	5.40	0.00	2.38	9.00	8.46	0.00	0.00	0.00	0.00	0.00	0.00	*Lucianorhabdus cayeuxii*
4.54	0.00	16.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*Lucianorhabdus maleformis*
0.00	0.00	0.00	2.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*Microrhabdulus decuratus*
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.33	0.00	0.00	0.00	*Micula concava*
4.54	8.10	16.70	13.09	24.00	30.76	0.00	0.00	0.00	0.00	0.00	0.00	*Micula decussata*
0.00	0.00	0.00	0.00	0.00	0.00	6.66	5.80	0.00	7.10	8.09	4.87	***Micula prinsii***
0.00	0.00	0.00	5.95	0.00	0.76	0.00	0.00	0.00	0.00	0.00	0.00	*Micula swastica*
0.00	4.05	0.00	3.57	2.00	2.30	0.00	14.28	16.66	0.00	0.00	0.00	*Quadrum gothicum*
0.00	8.10	0.00	0.00	2.00	1.53	0.00	0.00	0.00	0.00	0.00	0.00	*Reinhardtites levis*
9.09	0.00	5.40	8.20	0.00	4.05	0.00	0.00	0.00	0.00	0.00	0.00	***Uniplanarius sissinghii***
18.18	4.05	16.70	5.95	9.00	11.53	20.00	14.28	25.00	21.42	0.00	0.00	*Watznaueria barnesae*
9.09	24.38	11.29	17.99	20.00	9.15	0.00	0.00	0.00	0.00	0.00	0.00	*Watznaueria biporta*
4.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*Zeugrhabdotus erectus*
0.00	0.00	0.00	0.00	2.00	0.76	0.00	0.00	0.00	0.00	0.00	0.00	*Zeugrhabdotus noeliae*
U. sissinghii						*N. frequens*						**BIOZONES**
CC21						**CC26**						**NANNOFOSSIL ZONE** (Sissingh1977)

Discussion

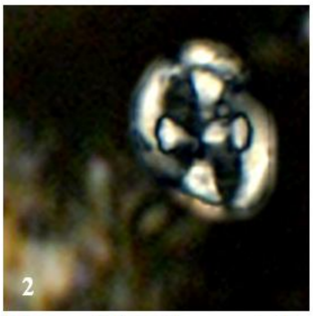
Paleoecology

Many authors have investigated the paleoecology of the upper Cretaceous. Some authors (e.g., Gradstein & Ogg, 2004; Frakes, 1979; Hallam, 1981, 1985; Henriksson & Malmgren, 1997) consider the Cretaceous to be a period of great warmth all over the globe. Tropical–subtropical conditions prevailed to at least 45°N and possibly to 70°S, with warm to cool temperateextending to the poles (Frakes, 1979; Hallam, 1981). Mean annual temperatures were significantly higher and latitudinal gradients existed about half of those of today. The Cretaceous has been generally viewed as a period of free ice-caps (Hallam, 1985; Francis & Frakes, 1993). Recent global stable isotope studies show that significant climatic and temperature fluctuations occurred in the Maastrichtian.

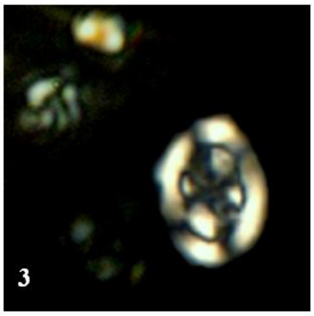
The long-term global cooling that characterizes the Maastrichtian (Douglas & Savin, 1975; Arthur *et al.,* 1985; Barrera *et al.,* 1997) is superimposed by dramatic climate and temperature fluctuations (Barrera & Savin, 1999; Li & Keller, 1999). In particular, the late Maastrichtian experienced the most extreme climate changes, including global cooling between 67.7 and 66 Ma, which decreased sea-surface temperature by 3 °C in middle to high-latitudes (Barrera & Savin, 1999; Li & Keller, 1998, 1999).



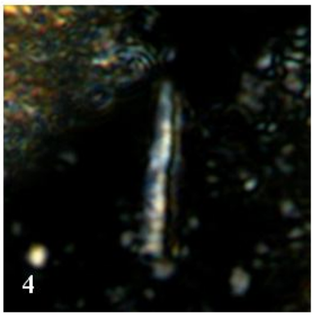
Arkhangelskiella specillata
Image # Kalat 5 (Ch)



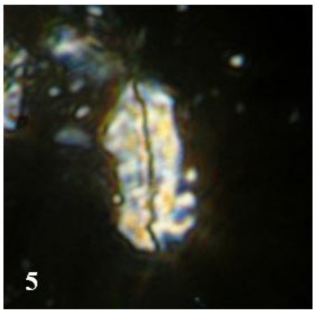
Arkhangelskiella cymbiformis
Image # Kalat 7 (Ch)



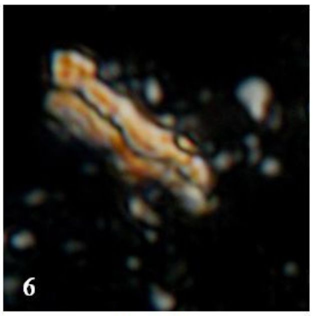
Arkhangelskiella cymbiformis
Image # Kalat 9 (K)



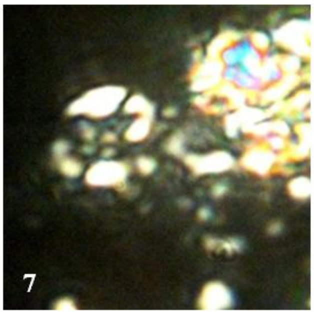
Acuturris scotus
Image # Kalat 7 (K)



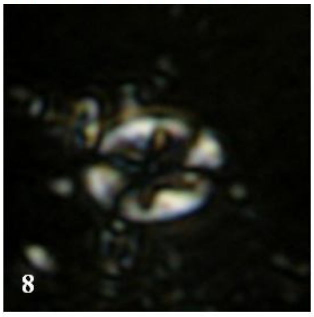
Lucianorhabdus cayeuxii
Image # Neyzar 2 (D)



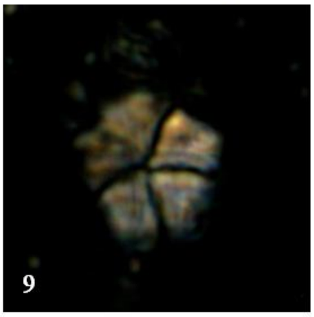
Lucianorhabdus cayeuxii
Image # Kalat 9 (Ch)



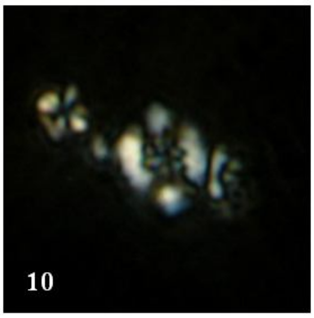
Eiffellithus gorkae
Image # Neyzar 4 (K)



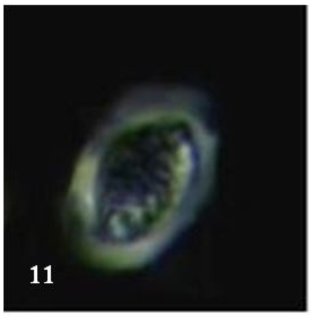
Eiffellithus turriseiffelii
Image # Kalat 9 (Ch)



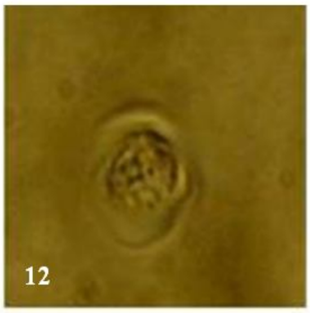
Braarudosphaera bigelowii
Image # Neyzar 4 (K)



Retecapsa angustiforata
Image # Kalat 8 (Ch)



Cribrosphaerella ehrenbergii
Image # Neyzar 2 (D)



Cribrosphaerella ehrenbergii
Image # Neyzar 2 (D)

Figure 7: All Figures light micrographs magnified X2500 (in this figure "D" is as a picture of fossil in the Dobaradar section, "K" in the Kalat section and "Ch" in the Chahchaheh section in eastern part of the Kopeh- Dagh Basin and "Q" is as a picture of fossil in the Qaleh Zoo section, "J" in the Jozak section and "Sh" in the Sheikh section in western part of the Kopeh- Dagh Basin.

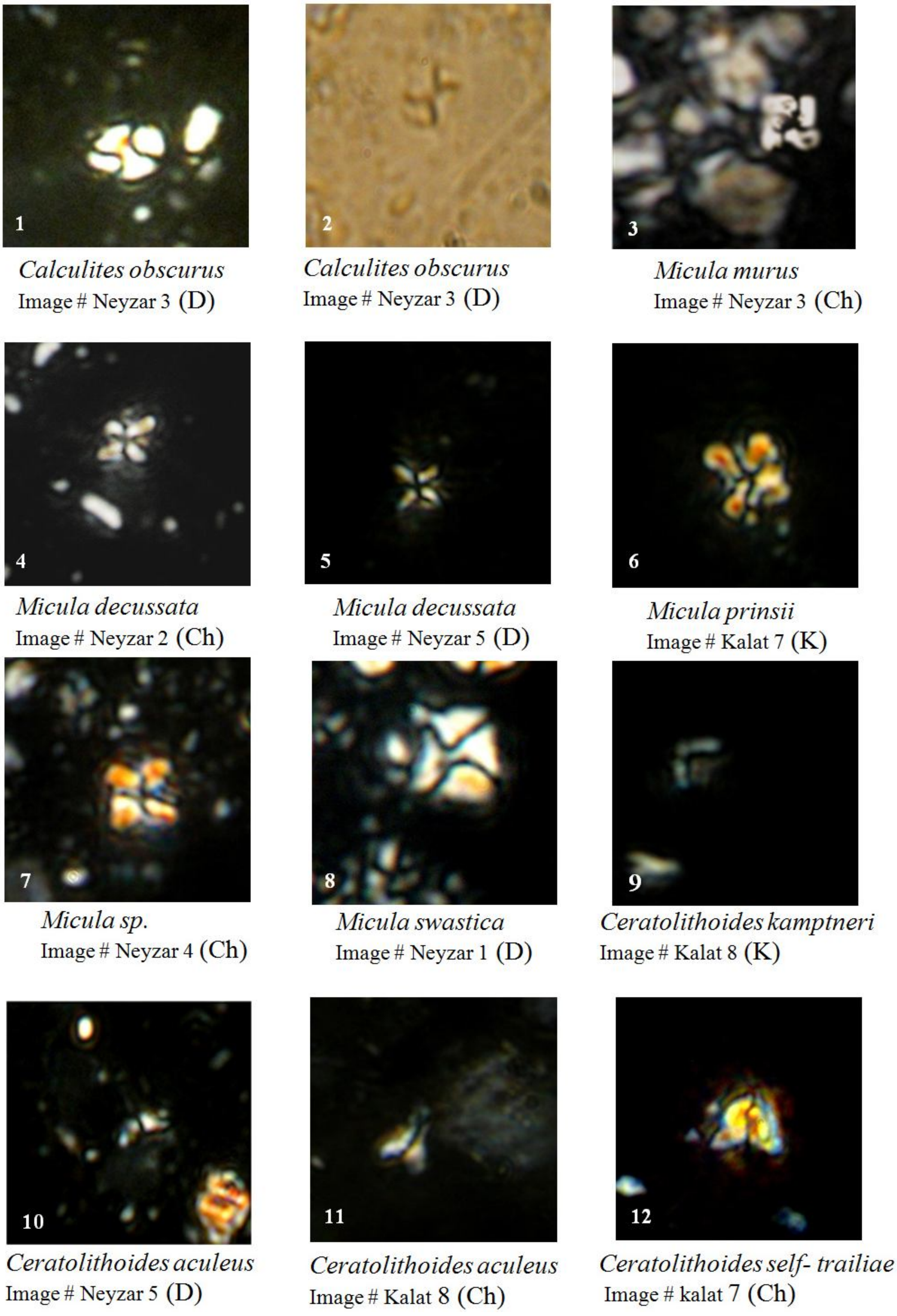


Figure 8: All Figures light micrographs magnified X2500 (in this figure “D” is as a picture of fossil in the Dobaradar section, “K” in the Kalat section and “Ch” in the Chahchaheh section in eastern part of the Kopeh- Dagh Basin and “Q” is as a picture of fossil in the Qaleh Zoo section, “J” in the Jozak section and “Sh” in the Sheikh section in western part of the Kopeh- Dagh Basin.

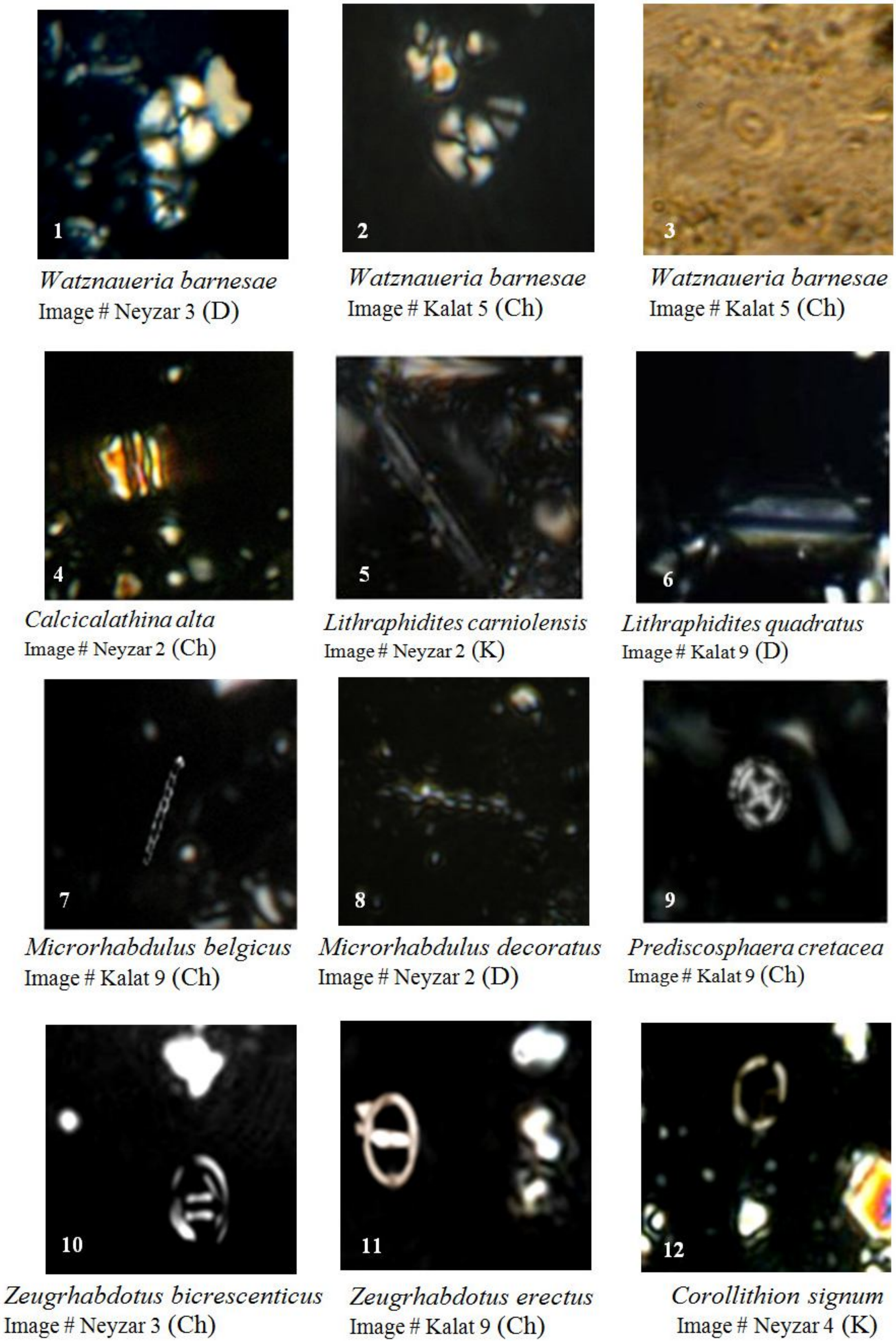


Figure 9: All Figures light micrographs magnified X2500 (in this figure "D" is as a picture of fossil in the Dobaradar section, "K" in the Kalat section and "Ch" in the Chahchaheh section in eastern part of the Kopeh- Dagh Basin and "Q" is as a picture of fossil in the Qaleh Zoo section, "J" in the Jozak section and "Sh" in the Sheikh section in western part of the Kopeh- Dagh Basin.

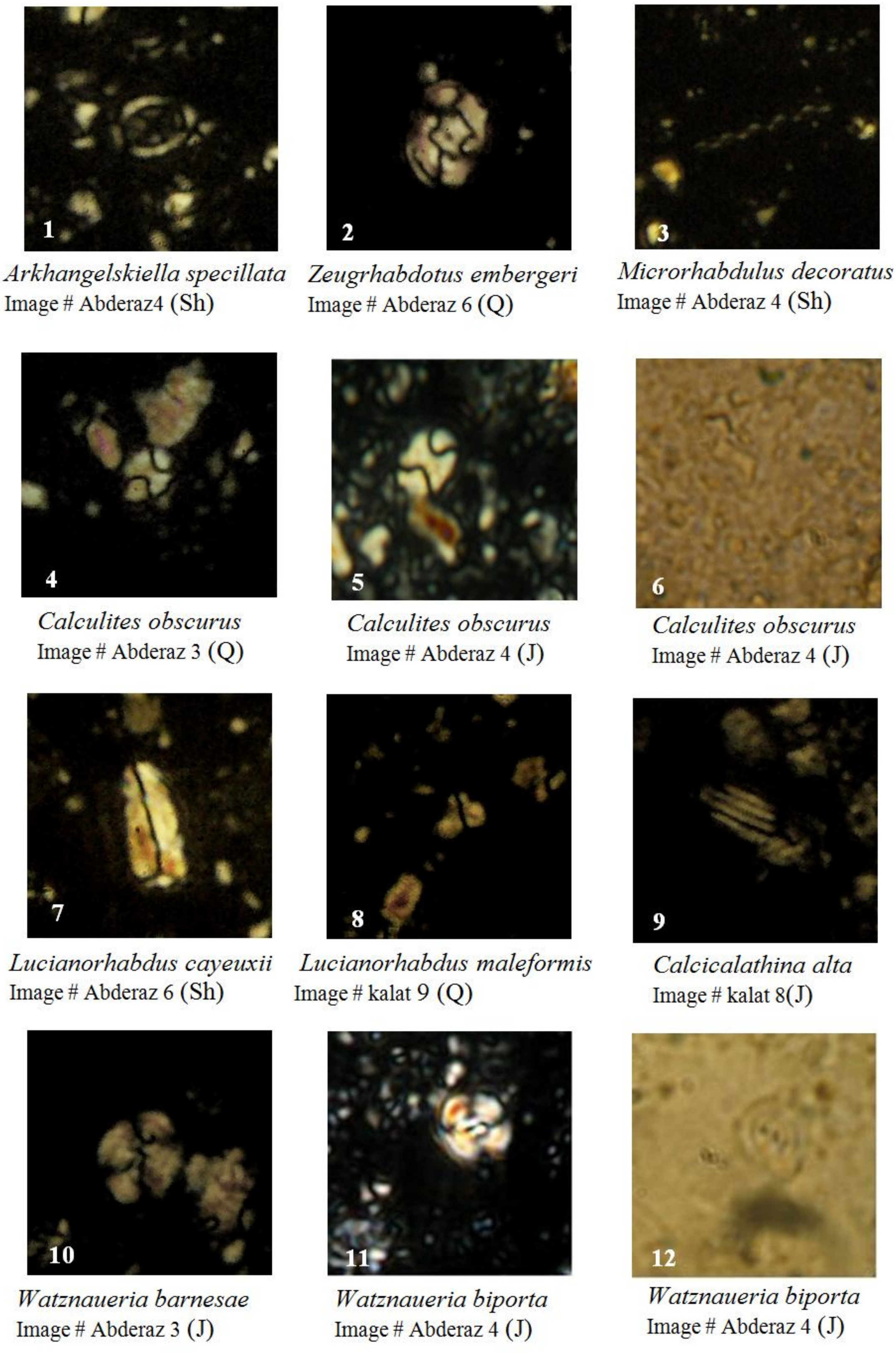


Figure 10: All Figures light micrographs magnified X2500 (in this figure “D” is as a picture of fossil in the Dobaradar section, “K” in the Kalat section and “Ch” in the Chahchaheh section in eastern part of the Kopeh- Dagh Basin and “Q” is as a picture of fossil in the Qaleh Zoo section, “J” in the Jozak section and “Sh” in the Sheikh section in western part of the Kopeh- Dagh Basin.

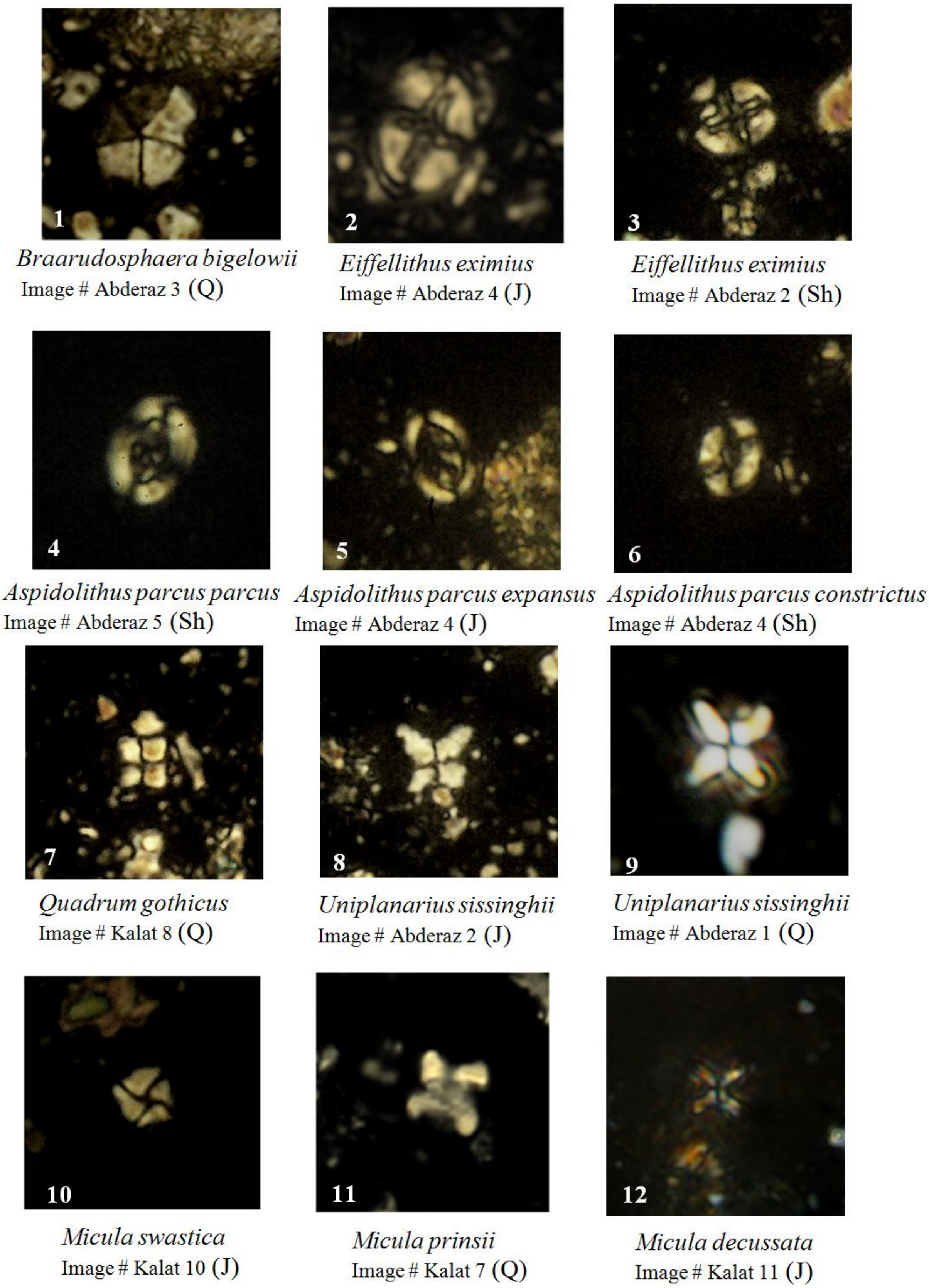


Figure 11: All Figures light micrographs magnified X2500 (in this figure "D" is as a picture of fossil in the Dobaradar section, "K" in the Kalat section and "Ch" in the Chahchaheh section in eastern part of the Kopeh- Dagh Basin and "Q" is as a picture of fossil in the Qaleh Zoo section, "J" in the Jozak section and "Sh" in the Sheikh section in western part of the Kopeh- Dagh Basin.

This cooling was followed by a rapid and intense warming of 3–4 °C (65.4-65.2 Ma) before the Cretaceous–Paleogene boundary (K–PB) (Barrera & Savin, 1999; Li & Keller, 1999 , 1998) and correlated with the timing of the main eruptive episode of Deccan volcanism, which could have caused greenhouse conditions (Barrera & Savin, 1999; Li & Keller, 1999; Ravizza & Peucker-Ehrenbrink, 2003).

This paper presents new calcareous nannofossil data from the lower boundary of the Kalat formation in the west and east of the Kopeh- Dagh Basin. It shows temperature, fertility, and nutrient indices relative to the Maastrichtian in this boundary.

Micula Decussata: A High-stress Marker?

The nannolith *M. decussata* is a major component of Late Cretaceous assemblage. According to Thierstein, 1980, 1981, *M. decussata* is a highly dissolution- resistant form and is considered as a good indicator of poor nannofossil preservation and diagenetic enhancement (Roth, 1983; Pospichal, 1991; Pospichal & Wise, 1990; Eshet & Almogi Labin, 1996). Since the studies of Hill, 1975 and Thierstein, 1980, its distribution has largely been interpreted as driven by preservation. Some authors e. g., Eshet *et al.,* 1992; Tantawy, 2002 reported very high abundances of this species in well-preserved uppermost Maastrichtian samples, which show no evidence of dissolution or overgrowth. Eshet *et al.,* 1992; Gardin & Monechi, 1998; Tantawy, 2002; Thibault & Gardin, 2006; interpreted the large predominance of *M. decussata* as indicative of high-stress environmental conditions. In the studied sections, the high abundance of *M. decussata* does not appear to be an artifact of dissolution because most other species, including dissolution-prone forms (e.g., *Prediscosphaera cretacea* and *Cribrosphaerella ehrenbergii*), are well preserved. Therefore, high abundance of *M. decussata* in samples with good preservation shows no evidence of strong dissolution or overgrowth. Hence, the high abundances of *M. decussata* in well-preserved assemblages in uppermost part of the Maastrichtian sediments are due to high-stress marine environments.

Temperature Indices

The calcareous nannofossils are sensitive indicators of changes in the sea surface temperature. *M. murus* and *M. prinsii* are restricted to warm waters (Worsley & Martini, 1970; Thierstein, 1981; Watkins *et al.,* 1996; Lees, 2002) and they could be considered as warm-water indicators, while *Ahmuellerella octoradiata*, *Gartnerago segmentatum*, *Kamptnerius magnificus,* and *Nephrolithus frequens* are predominantly high-latitude taxa and sporadically occur in low latitudinal area (Thierstein, 1976, 1981; Wind, 1979; Pospichal & Wise, 1990, Lees, 2002). These species, which are much more frequent at high-latitudes, are certainly the best indicators of cool surface waters.

Within the upper part of the Cretaceous, calcareous nannofossil assemblages such as, *W. barnesae* and *Uniplanarius sissinghii* are known to bear low latitude, and thus have warm water signal (Bukry, 1973, Thierstine, 1981, Wind & Wise, 1983, Wind, 1979, Watkins, 1992, Watkins *et al.,* 1996).

In the present study, in Late Maastrichtian, most of the observed nannofossils contain low to middle latitude taxa, which can live in warm water. Consequently, the appearance of these taxa, especially the presence of *M. prinsii*, *M. murus*, *W. barnesae,* and *U. sissinghii*, and absence of cool water indicators, show that the studied basin is linked to increasingly warm conditions.

Nutrient Indices

In calcareous nannofossil assemblages, some species are closely related to surface water productivity; they are good indicators of surface water productivity (Roth & Krumbbach, 1986; Erba, 2006, 2004; Erba *et al.,* 1992). The abundance and composition of nannofossil assemblages should help to determine the trophic regime of surface water masses in the Maastrichtian (Eshet & Almogi-Labin, 1996). Diversification should be favored by low-nutrient availability, coupled with stable conditions.

Biscutum spp. was used to establish the high nutrient index corresponding to eutrophic conditions. *Lithraphidites carniolensis*, and *W. barnesae* were used for the medium nutrient index, related to mesotrophic conditions (Roth & Krumbach, 1986; Erba *et al,* 1992), *Eiffelithus* spp. and *Prediscosphae*ra spp. were used for oligootrophic conditions (Premoli-Silva *et al.,* 1989). *W. barnesae* is a cosmopolitan species, which is generally dominant in tropical latitudes. Several authors used it as a warm-water indicator

(Doeven, 1983; Watkins *et al.,* 1996; Watkins & Self-Trail, 2005; Boersma & Schackleton, 1981), which are able to live in medium to low nutrient conditions (Roth and Krumbach, 1986, Erba, 1990, Erba *et al.,* 1992, Lamolda *et al.,* 1992, Fischer & Hay, 1999). Other common taxa of Maastrichtian assemblages such as *C. ehrenbergii* and *Retecapsa* spp. do not show any latitudinal preferences nor seem to be related to surface water productivity (Premoli-Silva *et al.,* 1989). Thus, the significance of their distribution patterns remains unknown. In the present study, the presence of species with low productivity such as *Eiffelithus* spp., *Prediscosphae*ra spp., *Lithraphidites* spp., and *W. barnesae*, and the absence of species that indicate high productivity such as *Biscutum* spp., refer to low surface water productivity conditions for this basin in the Maastrichtian.

Conclusions

The calcareous nannofossil data from the lower boundary of the Kalat formation provide information on driving mechanisms of the upper Cretaceous sediments in the Kopeh- Dagh basin. Environmental changes reconstructed from our internally consistent proxy data comprise variations in temperature and nutrient. The results of our study are as follows:

1. Nannofossil species in the studied sections in the east and west are relatively medium in abundance and diversify with high preservation in the east and high to moderate preservation in the western part of the Kopeh- Dagh Basin.
2. Based on calcareous nannofossils, the age of the studied interval is Late Maastrichtian - late Late Maastrichtian in the east, and early Late Campanian - late Late Maastrichtian in the west of the Kopeh-Dagh Basin.
3. According to this investigation and based on the calcareous nannoplankton zones, CC25 continues from the uppermost part of the Neyzar formation to the lower part of the Kalat formation in the east. A continuous sedimentary sequence across the Neyzar and Kalat formations boundary was suggested in these sections. However, in the west, based on the lack of CC22- CC23- CC24 and CC25 zones between the uppermost part of the Abderaz Formation and the lower part of the Kalat Formation, a discontinuous sedimentary sequence across the Abderaz and Kalat formations was determined.
4. The increase of the *M. decussata* in the Maastrichtian suggests the onset of high-stress environmental conditions.
5. Warm water temperature in the Maastrichtian in this basin is suggested by warm water indices such as *U. sissinghii*, *M. murus* and *M. prinsii.*
6. The absence of the productivity index taxa such as *B. constans*, in this interval and the number of species with low productivity such as *Eiffelithus* spp., *Prediscosphae*ra spp., *Lithraphidites* spp., and *W. barnesae* suggest lower productivity at the end of the Maastrichtian.
7. In calcareous nannofossil assemblages at the studied sections, *W. barnesae* and *L. carniolensis* indicate low to medium nutrients, which is related to mesotrophic conditions.

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