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Late Maastrichtian Calcareous Nannofossil Biostratigraphy and Paleoecology of the Tamera Well, Siwa Area, Western Desert, Egypt

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ABSTRACT

The upper Cretaceous interval of the Khoman Formation in the Tamera well, Siwa area, Western Desert of Egypt was studied for the first time on the basis of calcareous nannofossils. Twenty-one nannofossil species were identified from this interval. The study interval includes the *Micula murus* Zone, which is precisely dated as Late Maastrichtian age. The *Micula murus* Zone includes besides the marker species: *Micula decussata*, *Watznaueria barnesae*, *Arkhangelsktella cymbiformis* and relatively rare occurrences of *Eiffellithus turrisieffellii*, *Cribrosphaerella ehrenbergii*, *Thoracosphaera operculata* and *Braarudosphaera bigelowii*. The latest Maastrichtian *Micula prinsi* Zone is missing, and an unconformity surface is detected in this well. The high abundance of *Micula decussata* is indicative of very low surface productivity and high-stress environmental conditions. Several nannofossil species are recognized as cool water indicators such as *Micula decussata*, and *Arkhangelsktella cymbiformis*.

Keywords: Formation; Nannofossils; Micula Prins; Late Maastrichtian

1. Introduction

The Siwa Oasis is one of the series of depressions that lies in the shadow of the great Marmarica Plateau. It has an east-west direction with its center about 300 km south of the Mediterranean coast and approximately 65 km east of the Libyan border. To the north it is bounded by an escarpment which rises to about 100 m above the floor of the depression. To the south of the depression a sand dune belt exists trending in a northwest-southeast direction. The depression extends from Lake Zeitun in the east to Lake Maraqi in the west by a total length of 76 km and a maximum width of 20 km. The Siwa area is approximately 980 km^2. The lower parts of the depression floor average about 10 to 18 m below sea level.

The northern escarpment mainly trends in an east-west direction, but between longitudes 26˚00' and 26˚30', it extends southward for about 30 km into a promontory that forms the dividing highland between the Siwa and Qattara depressions.

The Siwa area was subjected to serve tectonic events due to its location in the Unstable Shelf area. From the Paleozoic until the Cenozoic, the area was subjected to faulting and many of the faults were being rejuvenated from time to time [1].

The study well is located in northwestern of the Siwa Oasis (**Figure 1**). The aim was to investigate and assign the calcareous nannofossils of the upper part of the Khoman Formation (Maastrichtian) in the subsurface rocks of the Western Desert of Egypt.

2. Stratigraphy

The Cretaceous-Tertiary sedimentary succession, in the studied well at Siwa Oasis, is generally subdivided into seven lithostratigraphic units; three of them are related to the Neogene, namely Marmarica Formation (Middle Miocene), Mamura Formation (Lower Miocene) and Apollonia Formation (Paleocene-Middle Eocene); and the rest to the Cretaceous, namely Khoman (Chalk) Formation (Campanian-Maastrichtian), Abu Roash Formation (Turonian), Bahariya Formation (Cenomanian) and Burg El Arab Formation (Early Cretaceous). The Khoman Formation consists of chalky limestone, partly argillaceous, with few chert bands and containing few sand streaks at the base. The chalky limestone points to open marine sedimentation as a result to Upper Cretaceous marine transgression [2].

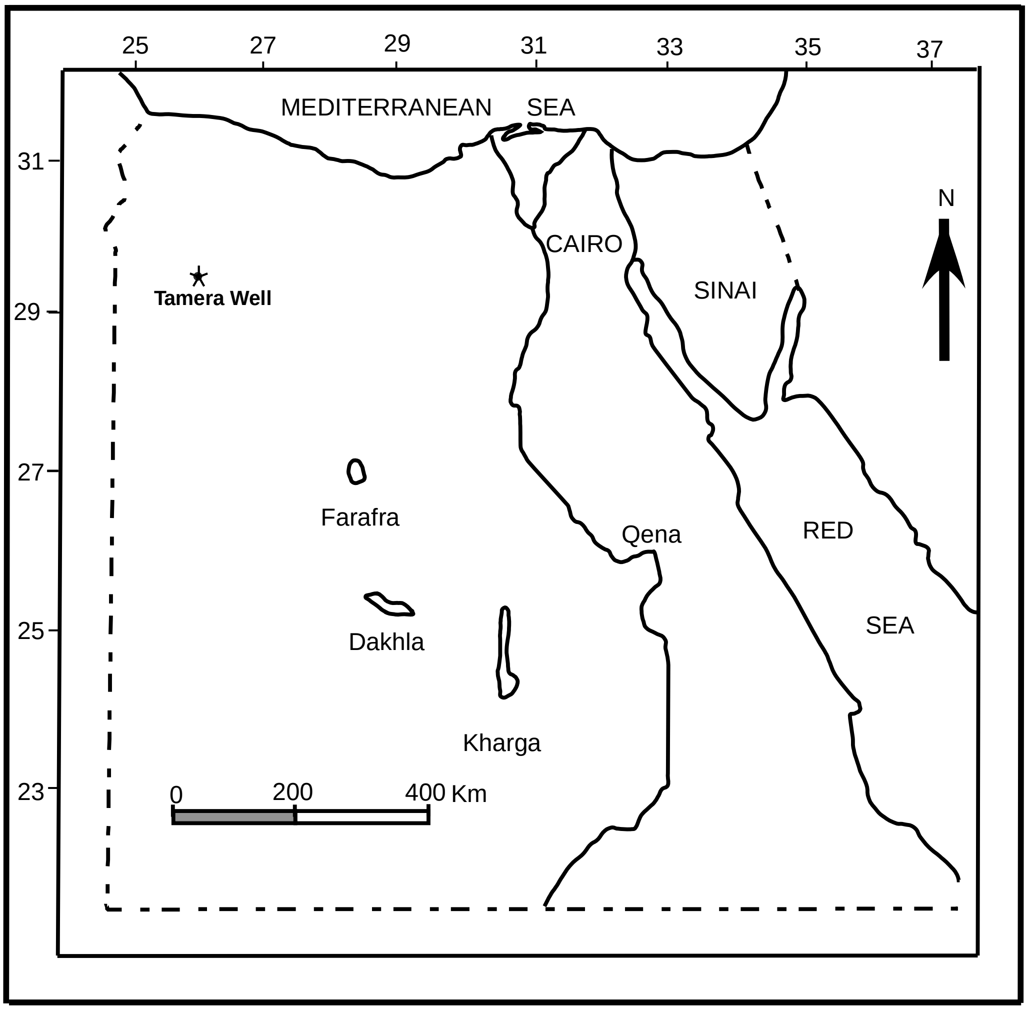

Figure 1. Location map of Tamera Well, Siwa Basin, Western Desert, Egypt.

In the southern part of the Siwa area, the Khoman Chalk is unconformably underlain by the Turonian rocks of the Abu Roash Formation that composed of coarse grained, subangular, fairly sorted sandstone. At Siwa Oasis, the formation is built up typically of limestone and dolomite. The limestone is finely crystalline, highly fractured, partly vuggy, and occasionally with calcite crystals in cavities.

In the north and northeastern parts of the Siwa area, the Khoman Formation is composed of soft and slightly calcareous shale that intercalated with argillaceous limestone. In such areas, the lithology reflects a near-shore to very shallow shelf environment, with a subsequent efficient fresh-water circulation [2].

In the study well, the upper part of the Khoman Formation consists mainly of shales, shaly limestone, and sandstone with shale intercalations (**Figure 2**).

3. Material and Methodology

A total of 56 samples were obtained from the upper part of the Khoman Formation of the Tamera well that located in the northwestern part of the Siwa area, Western Desert, Egypt. The samples were studied for their calcareous nannofossils. The relative abundances of the calcareous nannofossils were estimated from simple smear-slides following the methodology described in [3]. These slides were viewed at 1250× magnification, using an oil immersion objective lens on an Olympus light-microscope that equipped with automatic camera.

The relative abundances of the species were estimated over three traverses of each slide. The abbreviations used in this study are: few (F = 20 - 40 specimens), rare (R = 10 - 20 specimens), and very rare (VR = <10 specimens).

Preservation varies between moderate to poor: moderate (M = virtually all specimens are easily identifiable without secondary calcite overgrowth and/or calcite dissolution) and poor (P = depleted assemblage due to calcite dissolution and/or an appreciable proportion of specimens are difficult to identify due to calcite dissolution or secondary overgrowth.

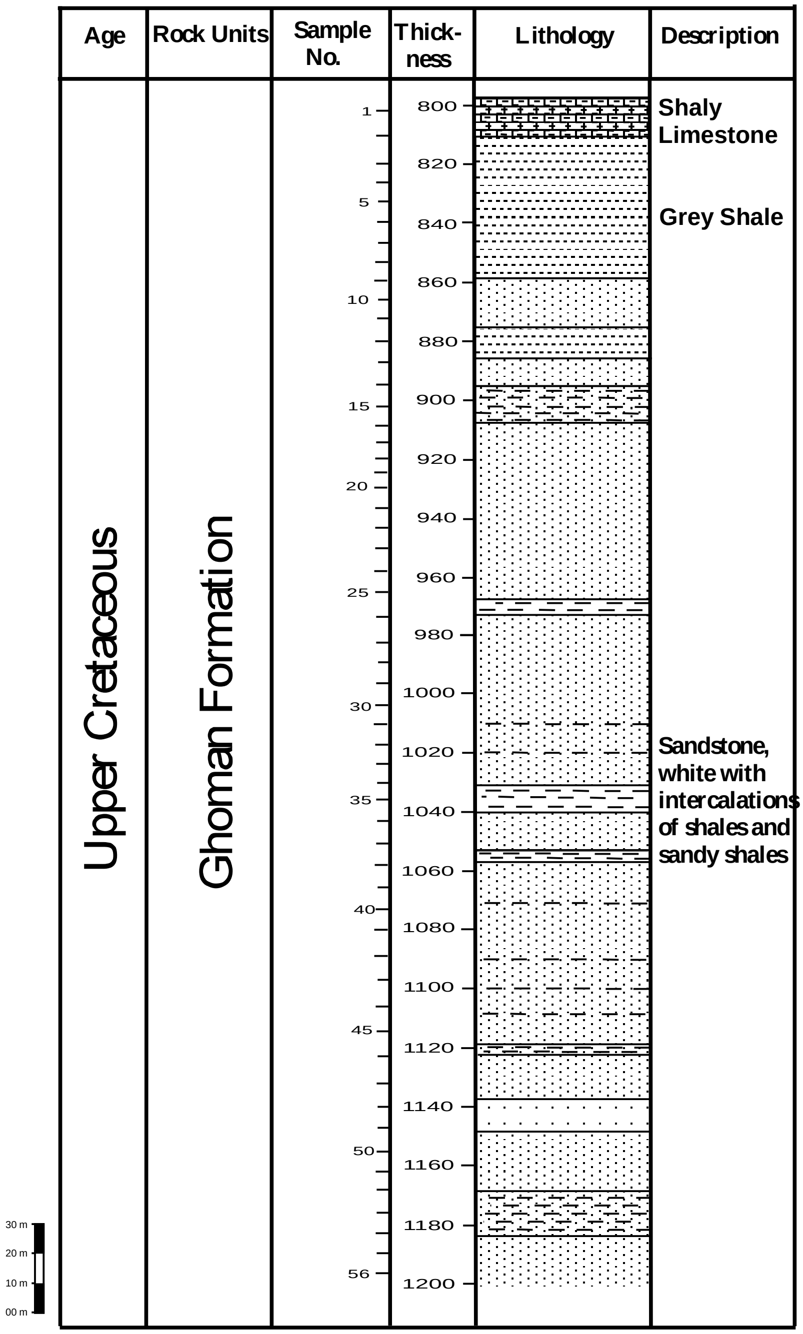

Figure 2. Stratigraphic section of Tamera Well, Siwa Basin, Western Desert, Egypt.

4. Nannofossil Biostratigraphy

In the present study, the biozonation scheme of [4], as modified by [5] was applied for the Maastrichtian sediments in the present study.

The distribution of the identified nannofossil taxa is shown in **Figure 3**, some representative nannofossil taxa are illustrated in **Plates 1** and **2**.

In the present study only one calcareous nannofossil biozone (*Micula murus* Zone) is identified. Details description of that zone is given in **Figure 3**.

***Micula murus* Zone:**

The *Micula murus* Zone was proposed by [6] and modified by [7]. It is identified from the lowest occurrence (LO) of *Micula murus* to the LO of *Micula prinsi*.

It is worth mentioning that the latest Maastrichtian interval is missing due to the absence of the calcareous nannofossil *Micula prinsi* Zone. The *Micula murus* Zone correlates with the lower part of the *Nephrolithus frequens* Zone [8] modified by [9] and the CC25c of [4]. [4] suggested a subdivision of CC25 Zone by the lowest

Age: Late Maastrichtian; Biozone: *Micula murus* Zone CC25c

Sample No.	56	55	54	53	52	51	50	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29
Abundance	B	B	B	B	B	B	R	B	F	B	B	B	B	F	B	B	B	B	B	VR	B	B	R	B	B	B	B	B
Preservation	-	-	-	-	-	-	M	-	M	-	-	-	-	M	-	-	-	-	-	M	-	-	P	-	-	-	-	-
Watznaueria barnesae							F		F					F						F			R					
Stradneria crenulata																												
Arkhangelskiella cymbiformis							R		R					R														
Micula decussata									F					F									R					
Eiffellithus turrisiefelii																				R								
Glaukolithus diplogrammus																												
Micrantholithus vesper														R														
Micula murus							R		VR					R						R								
Braarudosphaera bigelowii																												
Lucianorhabdus cayeuxii																												
Cribrosphaerella ehrenbergii									R																			
Reinhardtites levis																												
Rhagodiscus angustus																												
Microrhabdulus decoratus																												
Cyclagelosphaera reinhardtii									R																			
Zeugrhabdotus pseudanthophorus																												
Aspidolithus parca parca									R																			
Calculites obscurus																												
Qardum sp.									R																			
Thoracosphaera operculata																												
Reinhardtites anthophorus									R																			

Sample No.	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Abundance	B	B	B	B	B	R	F	VR	B	VR	B	B	B	B	B	B	B	B	B	B	B	B	VR	B	B	B	B	VR
Preservation	-	-	-	-	-	M	M	M	-	M	-	-	-	-	-	-	-	-	-	-	-	-	M	-	-	-	-	M
Watznaueria barnesae						R	F	R		F													R					F
Stradneria crenulata										VR													VR					VR
Arkhangelskiella cymbiformis							R			R																		
Micula decussata						F	F	F																				R
Eiffellithus turrisiefelii							R																					
Glaukolithus diplogrammus										R																		
Micrantholithus vesper						R																						
Micula murus							R																					R
Braarudosphaera bigelowii							VR																					
Lucianorhabdus cayeuxii						VR	F	VR																				F
Cribrosphaerella ehrenbergii							R																					
Reinhardtites levis							VR																					
Rhagodiscus angustus							R																					
Microrhabdulus decoratus							R																					
Cyclagelosphaera reinhardtii							R																					R
Zeugrhabdotus pseudanthophorus						VR																						
Aspidolithus parca parca																												
Calculites obscurus							VR																					
Qardum sp.																												
Thoracosphaera operculata							R																					
Reinhardtites anthophorus							VR																					

Figure 3. Distribution chart of the identified calcareous nannofossils in Tamera Well, Western Desert.

occurrence of *A. cymbiformis* and lowest occurrence of *L. quadratus*. **Figure 4** shows a comparison between the used zonal scheme and that applied by [4]. This zone is dominated besides the marker species by *Micula decussata*, *Watznaueria barnesae*, *Arkhangelsktella cymbiformis* and relatively rare occurrences of *Eiffellithus turrisieffellii*, *Cribrosphaerella ehrenbergii*, *Thoracosphaera operculata* and *Braarudosphaera bigelowii*.

5. Paleoecology

The Micula decussata is a major component of the Late Cretaceous nannofossil assemblage. Few authors reported very high abundances of this species in well-preserved taxa from different paleoecological conditions from different parts of the world. Several authors suggested that this taxon might have preferred cooler temperatures [10-12]. However, biogeographic studies of [10,13-16] showed that this taxon is clearly cosmopolitan and can reach as far as 80% in both tropical and sub-tropical assemblages. [17,18] interpreted the high abundances of *Micula decussata* as indicative of very low surface productivity and high-stress environmental conditions.

Several nannofossil species are recognized as cool water indicators. These are mainly *Arkhangelsktella cymbiformis*, [10,13] referred *Arkhangelsktella cymbiformis* as a high-latitude taxon. However, [16] shows that this species is common down into tropical paleolatitudes, although it prefers high-latitudes.

Micula murus is clearly restricted to warm tropical waters and is totally absent from the high-latitude areas, all along its biostratigraphical range [13,16,19,20]. Thus, it could be considered as a good warm-water indicator.

Some nannofossil species are good indicators of surface water fertility. *Watznaueria barnesiae* is a cosmopolitan species which is generally dominant in tropical latitudes and only common in high-latitude sites. Thus, several authors used it as a warm-water indicator [11, 12,20]. However, several studies showed that *Watznaueria barnesiae* is mainly a low-nutrient indicator [21-25]. Other common taxa of Maastrichtian assemblages such as *Cribrosphaerella ehrenbergii* do not show any latitudinal preferences nor seem to be related to surface water fertility.

A summary of nannofossil temperature and fertility indices is presented in **Table 1**.

In the investigated samples of the present well, the dominance of cool water nannofossil assemblages (*Micula decussata*, and *Arkhangelsktella cymbiformis*) may indicate cooling conditions that prevailed during the deposition of the Khoman Formation.

Age		[4]	Bioevents	Present study
Maastrichtian	Late	CC26	LO. *M. prinsii* LO. *N. frequens*, *C. kamptneri*	Hiatus
		CC25	c-LO. *M. murus*	
			b-LO. *L. quadratus*	Hiatus
			a-HO. *R. Levis*	Hiatus
	Middle	CC24	HO. *T. phacelosus*, *Q. trifidum*	Hiatus

Figure 4. Maastrichtian calcareous nannofossil events in the studied well and that of [4]. (HO. Highest Occurrences, LO. Lowest Occurrences).

Table 1. Calcareous nannofossil paleoecological indices considered in this study (compiled from different sources).

Fertility indices		Temperature indices	
High-fertility taxa	**not detected**	**Cool water taxa**	*Arkhangelsktella cymbiformis*
Mid-fertility taxa	**not detected**	**Warm-water taxa**	*Micula murus* & *Watznaueria barnesiae*
Low-fertility taxa	*Watznaueria barnesiae*		

6. Discussion and Conclusions

This study is considered the first attempt to study the nannofossil taxa of the Khoman Formation in the Tamera well, Western Desert of Egypt. Twenty-one nannofossil species have been identified in this study. The study interval (the upper part of the Khoman Formation) includes the *Micula murus* Zone, which is precisely dated by means of its calcareous nannofossils as Late Maastrichtian age. The *Micula prinsi* Zone of the latest Maastrichtian age is missed in the study well.

The Watznaueria barnesiae and *Micula decussata* are considered as two high solution-resistant species and are generally used to test the preservation degree of the assemblage [26,27].

Throughout the Cretaceous, *the Watznaueria barnesiae* is rare to frequent in the study samples and considered to be a eurytopic cosmopolitan species as previously mentioned by [28-30].

In the present core samples, the dissolution resistsnt *Watznaueria barnesae* is rare to frequent and it is considered to be a good index taxon to indicate alteration of the assemblages.

Watznaueria barnesae seems to also be more characteristic of low-mid latitude areas, being rare in high-latitude sites.

It is probable that differing paleoceanographic conditions (*i.e.* paleotemperature, paleosalinity, fertility fluctuations) affected the relative abundant of *Watznaueria barnesae*.

On the other hand, the distribution of *Watznaueria barnesiae* seems to be a good indicator of surface water fertility changes and recently have been used as nannofossil fertility index [31,32]. During the Maastrichtian, this species is generally rare or absent from high-latitude assemblages [33-35]. Moreover, it seems that temperature might also have played a significant role in the distribution of this taxon (*Watznaueria barnesiae*).

The Micula murus is a rare component of the Maastrichtian calcareous nannofossil assemblages in the study well. The dominance of cold nannossil assemblages in the studied upper Maastrichtian interval may suggest cool surface water paleotemperature during this time.

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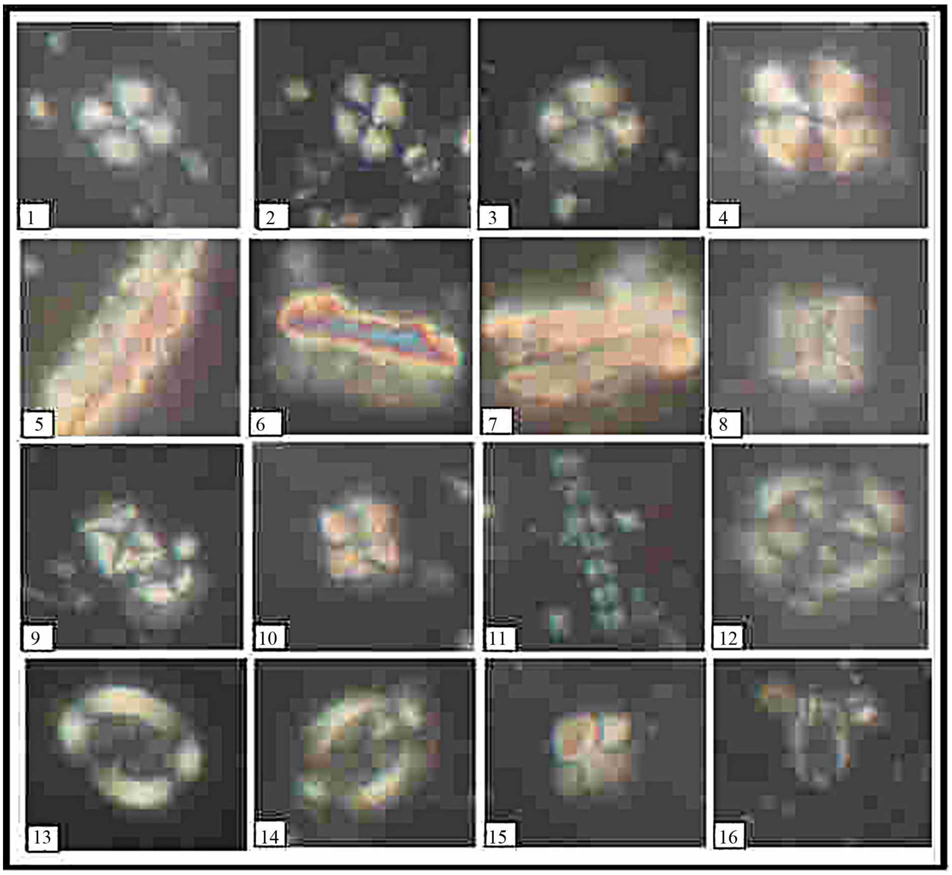

Plate 1. All figures ×1250. (1, 2, 3): *Watznaueria barnesae* [36], 1 sample No. 1, 2 sample No. 34, 3 sample No. 43; (4): *Cyclagelosphaera reinhardtii* [37], sample No. 48; (5, 6, 7): *Lucianorhabdus cayeuxii* [38], 5 sample No. 21, 6 sample No. 22, 7 sample No. 23; (8, 9, 10): *Micula decussata* [39], 8 sample No. 34, 9 sample No. 43, 10 sample No. 48; (11): *Microrhabdulus decoratus* [38], sample No. 22; (12, 13, 14): *Arkhangelskiella cymbiformis* [39], 12 sample No. 19, 13 sample No. 22, 14 sample No. 50; (15): *Calculites obscurus* [38], sample No. 22; (16): *Cribrosphaerella ehrenbergii* [40], sample No. 48.

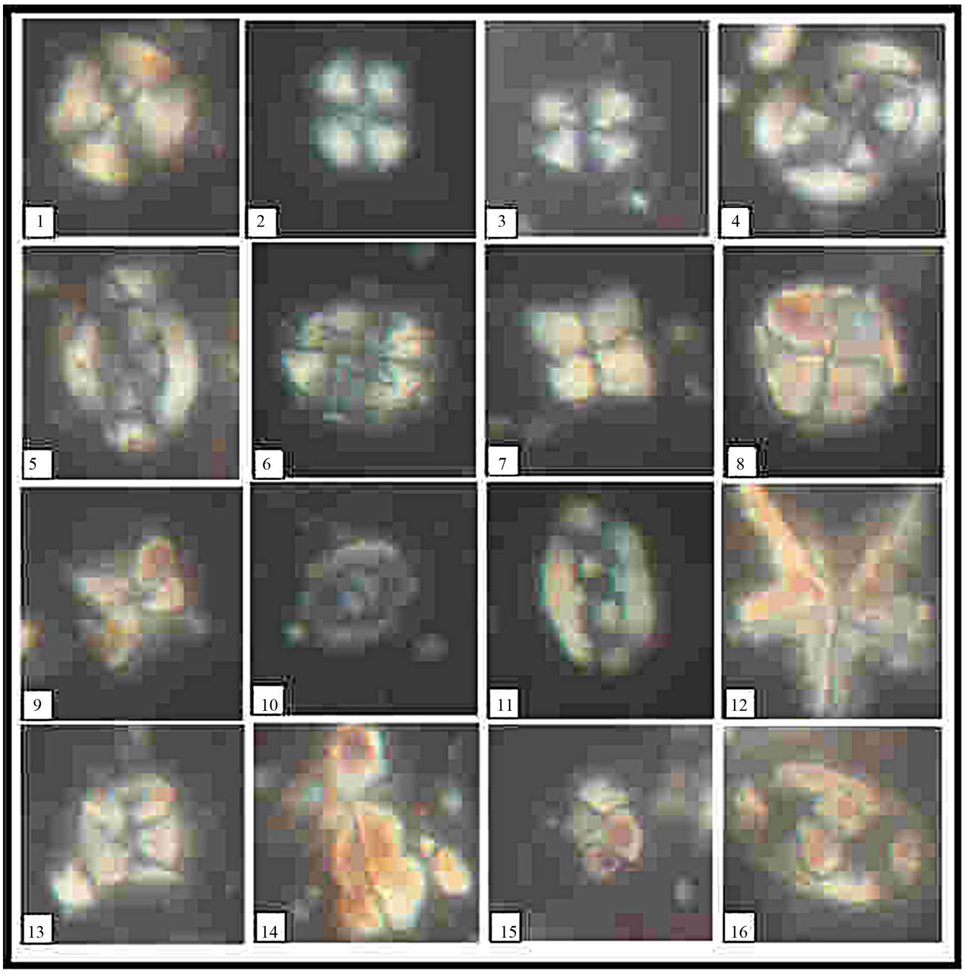

Plate 2. All figures ×1250. (1): *Cyclagelosphaera reinhardtii* [37], sample No. 1; (2, 3): *Watznaueria barnesae* [36], 2 sample No. 21, 3 sample No. 48; (4, 5): *Arkhangelskiella cymbiformis* [39], 4 sample No. 43, 5 sample No. 50; (6): *Eiffellithus turrisiefelii* [41], sample No. 37; (7, 8): *Micula murus* [42], 7 sample No. 1, 8 sample No. 37; (9, 13): *Micula decussata* [39], 9 sample No. 21, 13 sample No. 34; (10): *Glaukolithus diplogrammus* [41], sample No. 19; (11): *Rhagodiscus angustus* [43], sample No. 22; (12): *Micrantholithus vesper* [41], sample No. 43; (14): *Lucianorhabdus cayeuxii* [38], sample No. 21; (15): *Calculites obscurus* [38], sample No. 22; (16): *Zeugrhabdotus pseudanthophorus* [44], sample No. 23.

