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Upper Cretaceous Nannofossils Biostratigraphy from Cyrenaica, NE Libya.

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Highlights

- **The retrieved calcareous nannofossils from the surface outcrop and the Well E1-NC152 are identified to date the penetrated successions.**
- **The age is assigned to the Cretaceous (late Albian – early Campanian) due to the recognized five calcareous nannofossils biozones.**
- **A correlation of the established biozones with the published works in nearby areas is also attempted.**

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ABSTRACT

The Upper Cretaceous succession of the Well E1-NC152 in the Soluq Depression area of Cyrenaica region in Northeastern Libya, as well as the surface exposure of the Qasr al Abid Formation in Jardas al Abid area of Cyrenaica, have been biostratigraphically analyzed. The studied section of well E1-NC152 is assigned to the early Cretaceous (late Albian) – late Cretaceous (early Campanian) of Nannofossil Biozones (CC9 to CC22) of Sissingh (1977) and Perch-Nielsen (1985) which is respectively corresponding to UC5 to UC14 Biozones of Burnett (1998). These biozones are *Calculites ovalis* (CC19) – *Quadrum trifidum* (CC22) (early-late Campanian); *Calculites obscurus* Biozone (CC17) – *Aspidolithus parcus gr. parcus* Biozone (CC18) Late (Santonian– Early Campanian); *Reinhardtites anthophorus* Biozone (CC15) - Lucianorhabdus cayeuxii (CC16) (Santonian according to Sissingh (1977); *Lucianorhabdus maleformis* Biozone (CC12) - *Micula decussata* Biozone (CC14) (middle Turonian – middle Coniacian); *Eiffellithus turriseiffilii* Biozone (CC9) – *Microrhabdulus decorates* Biozone (CC10a) (late Albian – Cenomanian). However, the upper Cenomanian Qasr al Abid Formation at the outcrop is assigned to CC10a of Sissingh (1977) and Perch-Nielsen (1985) which is corresponding to UC3 (a-d) of Burnett (1998). Furthermore, correlation attempts with other published studies in the region have been performed to tie surface with the subsurface calcareous nannofossils distribution.

1. Introduction

The Al Jabal al Akhdar anticlinorium is a major geological feature in the northeastern part of Libya on the Mediterranean foreland of the African Shield. The upper Cretaceous carbonates of the Qasr Al Abid samples have been examined for their calcareous nannofossils contents. The location of the studied Well E1-NC152 as well as other surface outcrops together with the mentioned previously studied well are shown in Fig. 1.

The stratigraphical relationship between the exposed Qasr Al Abid, Al Baniyah, Al Majahir, Al Hilal, and Athrun formations, are shown in Fig. 2, Qasr Al Abid Formation was believed to be equivalent to the lower part of the exposed Al Hilal Formation at Marsa al Hilal type locality (Barr, 1972). Regional geological mapping in northern Cyrenaica (Klen 1974; Rohlich 1974; Mazhar and Issawi 1977; El Deftar and Issawi 1977) have indicated that erosional unconformities have discriminated the upper Cretaceous rocks into distinguished formations.

The stratigraphic chart (Fig. 2) shows that the upper Cretaceous sequence in the north Cyrenaica is bounded by two major unconformities. The lower one has been recorded in the subsurface, while the upper one marks the boundary with Paleogene exposures (El- Hawat *et al.*, 1980) in Athrun area; El Mehaghag and El Mehdawi (2006) in al Ahtrun section; Muftah *et al.* (2017); Abdulsamad *et al.* (2018) in Tobruq-Burdi area.

The Al Hilal Formation is passing upward and laterally into Athrun Formation (Barr and Hammuda, 1971; Barr, 1972; Rohlich, 1974). El Mehaghag and Muftah (1996) however, limited the age of these two formations to Santonian and Campanian respectively. In the southern structural inliers, the Santonian unconformity separates the upper Cretaceous into two sets of formations, each set with conformable contact. These are the Qasr al Abid and Al Baniyah formations; and Al Majahir and Wadi Dukhan formations (Fig. 2) (Klen 1974; Rohlich 1974; Rohlich *et al.*, 1998).

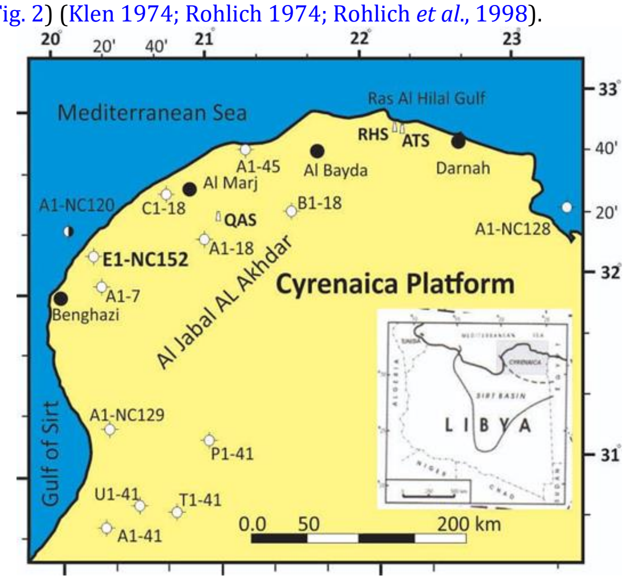

Fig. 1. Index map of Libya and location map showing the studied Qasr Al Abid section (QAS), Ras Al Hilal Section (RHS), Athrun Section (ATS), Studied Well E1-NC152, and other mentioned well (Modified after Keegan and Mansouri, 2007).

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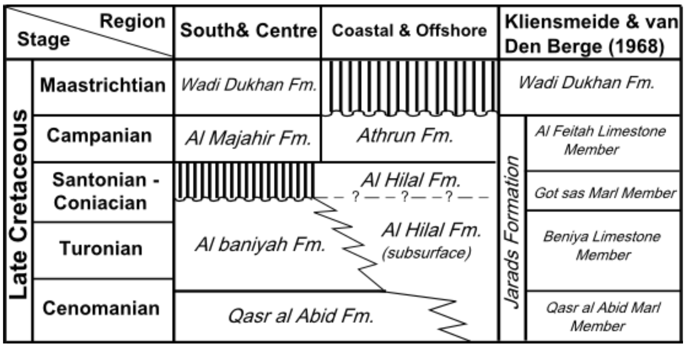


Fig. 2. Surface stratigraphic relationship of Cretaceous rock units in Al Jabal al Akhdar, NE Libya (Modified after Barr and Weegar (1971).

The Qasr al Abid Formation is exposed in the core of Jardas al Abid inlier and near Taknis village. An unconformity marked the lower boundary of the Cenomanian as predicted from logs of drilled oil wells (C1-18, A1-18, and B1-18), the thickness of the Cenomanian in these wells are 120, 150, and 167 m. respectively. Klen (1974) and Rohlich (1974) assigned the surface outcrops of this transgressive marl and marl limestone into the early Cenomanian age, however, Abdel-Gawad (2008) indicated the late Cenomanian age to the same outcrops based on invertebrate macrofossils (*Ammonites*). The main inversion event in north Cyrenaica took place during Santonian time (El Hawat and Abdulsamad, 2004). This event formed the major unconformity that separates the Cenomanian – Coniacian, Baniyah Formation from the Campanian sequence of Al Majahir Formation. Duronio *et al*., (1991) stated that offshore well A1-NC120 near Benghazi; the inversion events are indicated by the occurrence of shallow marine Campanian unit of Al Majahir Formation which lies between the deeper marine units; Al Hilal and Al Athrun formations. In the coastal area, Ras al Hilal and Al Athrun sections appear to be uninterrupted, as they were deposited in deep neritic to bathyal water conditions. The thickness of the Al Hilal and Athrun formations is remarkably thinner than its equivalents to the south. In a paleogeographic belt extending further seaward of C1-18 and the A1-NC120 offshore well, the total upper Cretaceous thickness is about 530 to 550m respectively (El-Hawat and Shelmani, 1993) Further to the east in the offshore well A1-NC128 the upper Cretaceous – lower Eocene sequences are missing altogether suggesting emergence and intensive erosion possibly since late Cretaceous time (Duronio *et al*., 1991). The reduction of the Al Hilal and Athrun sections may be attributed to deeper water condensation correlated to the Turonian and the intra-Santonian unconformities (El-Hawat and Abdulsamad, 2004). Kleinsmeide and van den Berg (1968) proposed four members of the Jardas Formation in northeast Libya: the Qasr Al Abid Marl Member, the Al Benia Limestone Member, the Got Sas Marl Member, and the Al Feitah Limestone Member (Fig. 2). The Qasr al Abid Formation is present as two small inliers in the core of the Jardas al Abid dome (Röhlich, 1974). The lower boundary is not exposed in the study area, However, the upper boundary is sharp and conformable with Al Baniyah Formation (El Hawat and Shelmani, 1993) (Fig. 2). This Formation is equivalent to the subsurface part of Al Hilal Formation at coastal sections (Barr and Weegar, 1972) (Fig. 2). Banerjee (1980) documented a diverse foraminiferal assemblage from the Qasr Al Abid Formation, based on the examination of samples from several subsurface wells. The assemblage includes *Globigerellinoides aspera, G. ehrenbergi, Rotalipora cushmani, R. reicheli, Praeglobotruncana stephani, Heterohelix moremani, Hedbergella ex. gr. delrioensis, H. planispira, H. ex. gr. amabilis, Thomasinella punica,* and Lenticulina div. sp. The planktonic *Rotalipora cushmani* Biozone has been recognized by Muftah (2014) from the lower successions (≈6650'-7000') of Well D1-NC152 in the vicinity of Jardas al Abid area as suggested by the presence of the diagnostic planktonic foraminifera *Rotalipora cushmani*, in association with *R. greenhornensis, Praeglobotruncana stephani* and *P. gibba,* although, this Biozone is not reported in the Jardas al Abid schools outcrop. Duronio *et al*., (1991) reported early Cenomanian foraminifera such as *Rotalipora, Thomasinella,* and *Planomalina* from the subsurface offshore well A1-NC120. Abdel-Jawad, (2008) examined the late Cenomanian sediments at two sections, the school section of Jardas al Abid and Bahria Oasis in the Western Desert of Egypt using mollusks (*Ammonites*), also correlated the established *Ammonites* Biozones with that in the Tethyan region.

1.1. Objectives

The main objectives are:

1- Identification of the calcareous nannofossils in the studied succession of Well E1-NC152, and Qars al Abid school section, with particular attention to establishing the biozonations.

2- Using the international nannoplankton biozonal schemes of Burnett (1998); Sissingh (1977, 1978); Perch Nielsen, (1979, 1983, 1985) as well as local nannoplankton zonal schemes of Starkie (2007) herein.

3- Correlation of the present results with previous publications to integrate the relationship of the surface with subsurface in Cyrenaica.

1.2. Materials

Six outcrop samples were collected at 1m intervals as the sequence is somewhat homogenous, from an excavation in the Qasr al Abid Formation close to the Jardas School, near Jardas al Abid village about 24 km south of El Merj city in the northeastern part of Al Jabal al Akhdar anticlinorium. In addition to fifty-one ditch cuttings samples (5100'–9380') and four core samples from core#1 (9440-9447') from exploration Well E1-NC152 in the coastal area east of Benghazi (Fig. 4). Additional published studied from outcrops at Ras al Hilal area (El Mahaghag and Muftah, 1996) and Wadi Al Athrun sections (El Mehaghag and El Mehdawi, 2006) and the subsurface published data of cores from exploration wells A1-45, P1-41, U1-41, A1-41 by El Mehaghag (1996) and wells A1-7, A1-NC129, T1-41 by Starkie (2007) have been integrated herein.

1.2.1. The Calcareous Nannofossils Preparation Technique

The preparation technique used herein is following the Pipette Straw Slide Method, (Bown and Young, 1998). The surface and well-core samples were trimmed with a blade until a fresh surface was obtained. The samples were crushed in a paper towel to avoid contamination. The sample powder was then placed in a beaker and immersed with distilled water. The solution was stirred and left for some time to allow the sediments to disintegrate. A small amount of the suspension was decanted into a test tube and diluted with distilled water. A labeled glass slide was flooded with the suspension and dried on a hot plate. A coverslip was mounted using optical mounting media. All slides were examined with an Axio Plan2 universal Zeiss microscope at 1000x and 2500x magnification. Each slide was examined under cross-polarized and normal Light. Species were photographed using a Sony video camera CCD-IRIS/RGB and Mitsubishi VidoprinterCP.700 E (D). Some of the observed species are illustrated in Fig. 5 and Fig. 6. Estimation of the relative abundance of species present on the field of view was based on three traverses (El Mehaghag and Muftah, 1996). All identified species listed herein are found in the Perch-Nielsen (1985) and Bowen (1998).

2. Biostratigraphy

The Cretaceous calcareous nannofossils zonation is well established compared to the zonation of the Jurassic and Triassic. The Upper Cretaceous zonation schemes of Sissingh (1977, 1978) and Perch-Nielsen (1979, 1983, 1985) have established eighteen CC-Biozones (from CC9 to CC26) were major calcareous nanofossils Biozones from Cenomanian to Maastrichtian with further subdivisions in some Biozones based on FO's and LO's of the diagnostic zonal markers. However, the equivalent Cretaceous zonation scheme of Burnett (1998) in the Tethyan-Intermediate province is composed of twenty-one Biozones (UC0– UC20) with relevant sub-Biozones based on the FO's and LO's of the zonal markers. On the other hand, a local calcareous nannofossils zonation scheme has been published by Starkie (2007), where, nineteen Biozones (from LLC1 to LLC19) have been established from mainly ditch cuttings samples (LO's) and few core samples (FO's and LO's) from exploration oil wells in Northeast Libya. The abovementioned schemes have been used in this study.

2.1. Biostratigraphy of Qasr al Abid surface section

The calcareous nannofossils are poorly to moderately preserve due to overgrowth and the section yielded only a few specimens and rare species richness, which may be attributed to dissolution (Fig. 3). The samples fall into UC3a-d (upper Cenomanian) of Burnett (1998) based on the last occurrence of *Corollithion kennedyi* and the last occurrence of the two zonal markers *Helenia chiastia* and *Lithraphidites acutus* (Fig. 3).

2.2. Biostratigraphy of Well E1-NC152

The studied section of the Well E1-NC152 is ranged in age from the latest Albian to early Campanian. The established calcareous nannofossils biozones (Figs. 4, 6) in the well from top to bottom are:

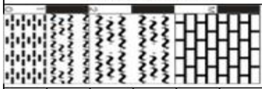
CC19 *Calculites ovalis* Biozone to CC22 *Quadrum trifidum* Biozone:
Age: early-late Campanian
Stratigraphic interval: 5100' – 5140'
Description: They are defined by the LO of *Marthasterites furcatus* (@5100') and the presence of the zonal marker *Eiffellithus eximius* (Fig. 4).

The important associated taxa included *Micula decussata, Gartnerago obliquum*, *Eiffellithus turriseiffelii, Tranolithus phacelosus*, and *Tranolithus gabalos* (Figs. 5, 7).

Remarks: The recognized zones CC19-CC22 in the studied well E1-NC152 are equivalent to that studied section at Wadi al Qalah section (El Mehaghag and Muftah, 1996). However, may correlate to *Quadrum trifidum* CC22 in the upper part of the Athrun Formation at Wadi al Athrun sections recovered by El Mehaghag and El Mehdawi (2006) and is correlatable to the calcareous nannofossil of the LLC11 to LLC14 in the local zonal scheme of Starkie (2007) in wells A1-7, A1-NC129, and T1-41 (Fig. 6).

CC17 *Calculites obscurus* Biozone to CC18 *Aspidolithus gr. parcus Biozone* of Sissingh (1977, 1978) and Perch Nielsen (1979, 1983, 1985) which are equivalent to UC12 –UC14 Biozones of Burnett (1998).
Age: late Santonian– early Campanian
Stratigraphic interval: 5140' – 5460'
Description: They are defined by the LO of *Marthasterites furcatus* (5140') to LO of *Eprolithus floralis* (5460') instead of using the FO of *calculites obscurus* due to its absence (Fig. 4). The important associated taxa included *Micula concavata, M. decussata, Lithraphidites carniolensis carniolensis, Eiffellithus turriseiffelii, Eiffellithus eximius, Tranolithus phacelosus*, *Lucianorhabdus cayeuxii,* and *Rhagodiscus angustus* (Figs. 5, 6).
Remarks: The interval of the established calcareous nannofossisl Biozones CC17-CC18 in Well E1-NC152, corresponds to CC16 - CC17 in core no. 33 of well A1-41 (El Mehaghag, 1996) and the upper part of the Al Hilal Shale (El Mehaghag and Muftah, 1996) (Fig. 6). The calcareous nannofossil Biozone of the upper part of the LLC9 to Biozone LLC10 in the local zonal scheme of Starkie (2007) is well correlated with the established Biozones CC17-CC18 of this studied well (Fig. 6).

CC15 *Reinhardtites anthophorus* Biozone to CC16 *Lucianorhabdus cayeuxii* of Sissingh (1977, 1978) and Perch Nielsen (1979, 1983, 1985) which are equivalent to UC11 – the lowermost portion of UC12 Biozones of Burnett (1998).
Age: Santonian according to Sissingh (1977). However, Burnett (1998) assigned the age to late Coniacian– early Santonian.
Stratigraphic interval: 5460' – 8010'

Jards Al Abid						Formation	
						Lithology	
1	2	3	4	5	6	Samples	
R					R	***Helenea chiastia***	
R				Barren		*Zeugrhabdotus ? noeliae*	Calcareous nannofossils
R						*Axopodorhabdus albianus*	
R					R	*Zeugrhabdotus scutula*	
R						***L. acutus***	
R					R	*Tranolithus orionatus*	
R					R	***Corollithion kennedyi***	
R						*Tegumentum stradneri*	
R						*Eiffellithus turriseiffelii*	
R						*Retecapsa crenulata*	
R						*Orastrum cf. O. perspicuum*	
R						*Owenia cf. O. hillii*	
R						*Biscutum ellipticum*	
R						*Watznaueria manivitiae*	
R					R	*Watznaueria biporata*	
R						*Zeugrhabdotus diplogrammus*	
R					R	*Watznaueria barnesae*	
R						*Thoracosphaera sp.*	
R						*Cyclagelasphaera reinhardtii*	
R						*Cyclagelasphaera deflandrei*	
C	C	R	R			***Thomasinella punica***	Foraminifers: Benthic
R	R	R	R			*Haplophragmoides spp.*	
F	F	R	R			*Gavelinella* sp.	
R			F			*?Rienholdella* sp.	
F		F	R			*Discorbis* sp.	
		F				*Conorotalites cf. C. aptiensis*	
		F	R			*Saracenaria* sp.	
	R	R				*Bigenerina* sp.	
			F			*Tolypammina* sp.	
R	F					*Osangularia* sp.	
F						*Hedbergella planispira*	Foraminifers: Planktic
F						*H. delrioensis*	
C						*H. amabilis*	
FO of *L. acutus* & LO of *C. kennedyi & H. Chiastia*						Nannofossils Events	
Burnett (1998) UC3 (a -d)						Nannofossils Zone	
Perch-Nelsen (1985) CC10							
Late Cenomanian						Age	

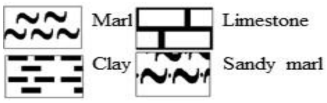


Fig. 3. Distribution chart of the recorded calcareous nannofossils and foraminifers from the studied Jardas (school section). (R: 1; F: 2-3; C: >3)

Description: They are defined by the LO of *Eprolithus floralis* (5460') to FO of *Reinhardtites anthophorus*? (8010') which represents FO of the species below the casing shoe. The LO of *Eprolithus floralis* is used herein instead of FO of *Calculites obscurus* which is not reported in the studied well (Fig. 4). Furthermore, the *Lucianorhabdus cayeuxii* zonal marker cannot be used to detect the boundary between the Biozones (CC15- CC16) due to the cuttings nature of the studied samples within this open-hole interval. It is the coeval of Burnett (1998) UC11-UC12 Biozones, although, the zonal markers *Lithrastrites grilli* and *L. septenarius* are not reported in this well. The important associated taxa included *Micula concavata, M. decussata, Lithraphidites carniolensis carniolensis, Eiffellithus turriseiffelii, Eiffellithus eximius, Tranolithus phacelosus*, *Lucianorhabdus cayeuxii,* and *Rhagodiscus angustus* (Figs. 5, 7).
Remarks: The upper part of the interval of the established calcareous nannofossil Biozones CC15-CC16 in Well E1-NC152, which is represented by CC16 is equivalent to the established Biozone (CC16) in core no. 1 of well U1-41 (El Mehaghag, 1996) and to the basal part of the Al Hilal Shale (El Mehaghag and Muftah, 1996) (Figs. 6, 8). The calcareous nannofossil Biozones of the upper part of the LLC7 to Biozone LLC8 in the local zonal scheme of Starkie (2007) in wells A1-7, A1-NC129, and T1-41 is well correlated with the established Biozones CC15-CC16 of this studied well (Fig. 6).

CC12 *Lucianorhabdus maleformis* Biozone to CC14 *Micula decussata* Biozone of Sissingh (1977, 1978) and Perch Nielsen (1979,

1983, 1985) which are equivalent to UC8a – UC10 Biozones of Burnett (1998).
Age: middle Turonian – middle Coniacian
Stratigraphic interval: 8010' – 8260'
Description: They are defined by the FO of *Reinhardtites anthophorus* (8010') to the FO of *Lucianorhabdus maleformis* (8260') which represents the FO of the species below the casing shoe. The FO of the two zonal markers is assumed to be *in-situ* as it presents below the casing point (Fig. 4). Most of the diagnostic taxa used by Burnett (1998) are absent. The important associated taxa included *Lithraphidites carniolensis carniolensis*, and *Lucianorhabdus* sp. (Figs. 5, 7).
Remarks: The upper part of the interval of the established calcareous nannofossil Biozones CC12-CC14 in Well E1-NC129, which is represented by CC14 is equivalent to the established Biozone (CC14) in core #2 of well U1-41 (El Mehaghag, 1996). The calcareous nannofossil Biozone of the upper part of the LLC4 to LLC6 Biozones in the local zonal scheme of Starkie (2007) in wells A1-7, A1-129, and T1-41 are well correlated with the established Biozones CC12-CC14 of the studied well (Fig. 6).
Barren Biozone
Age: early Turonian
Stratigraphic interval: 8260' – 8790'
Description: It occupies the interval from 8790' representing the base of CC10b Biozone of Sissingh (1977) as indicated by LO of *H. chiasta* which equivalent to the base of UC6 of Burnett (1998) to 8260' representing the top of CC11 Biozone of Sissingh (1977) as indicated by FO of *L. maleformis* (Fig. 4) which equivalent to the top of UC7 of Burnett (1998).
Remarks: This barren biozone is completely barren of any taxa, accordingly, it may stratigraphically represent the *Microrhabdulus decorates* Biozone (CC10b) to *Quadrum gartneri* Biozone (CC11). This may correspond to LLC3 and the lower part of LLC4 in the local zonal scheme of Starkie (2007) in wells A1-7, A1-129, and T1-41 (Fig. 6).

CC9 *Eiffellithus turriseiffilii* Biozone to CC10a *Microrhabdulus decorates* Biozone of Sissingh (1977, 1978) and Perch Nielsen (1979, 1983, 1985) which are equivalent to UC0/BC27 – UC5 Biozones of Burnett (1998).
Age: late Albian - Cenomanian
Stratigraphic interval: 8790' – 9447'
Description: These Biozones intervals in this Well are defined by the FO of *Eiffellithus turriseiffilii* (9447') to LO of *Helenea chiastia* (8790'). The presence of *Eiffellithus turriseiffilii* in the core # 1 (9447') defines the base of CC9 Biozone of Sissingh (1977) and UC0/BC27 of Burnett (1998), however, the presence of *H. chiastia* defines the top of the CC10a Biozone of Sissingh (1977) and UC5 of Burnett (1998). The absence of the zonal markers such as *Microrhabdulus decorates* and *Quadrum gartneri* obscures the boundary between the two Biozones (Fig. 4). The important associated taxa included *Zugodiscus pseudoanthrophorus*, *Litharaphidites alatus*, *Ahmuellerella octoradiata*, *Flabellites biforaminis* and *Corolithon* sp. (Figs. 5, 7)
Remarks: The lower part of the interval of the established calcareous nannofossisl biozones CC9-CC10a in well E1-NC152, which represented by CC9 is equivalent to the established Biozone (CC9 a-b) in core #1 of well P1-41 as well as cores # 1 and 2 of Well A1-45 (El Mehaghag, 1996). While, the upper part of the interval of the established calcareous nannofossisl Biozones 8730' is correlated with the established Biozone CC10a of the Qasr al Abid Formation at the Jarad al Abid studied outcrop (Figs. 3, 6). The calcareous nannofossil Biozones LLC1 and LLC2 in the local zonal scheme of Starkie (2007) are well correlated with the established Biozones CC9-CC10 of this studied well (Fig. 6).

All taxa are fully referenced in Perch-Nielsen (1985) and Bown (1998). Some taxa including key taxa are illustrated in Figs. 3 and 5.

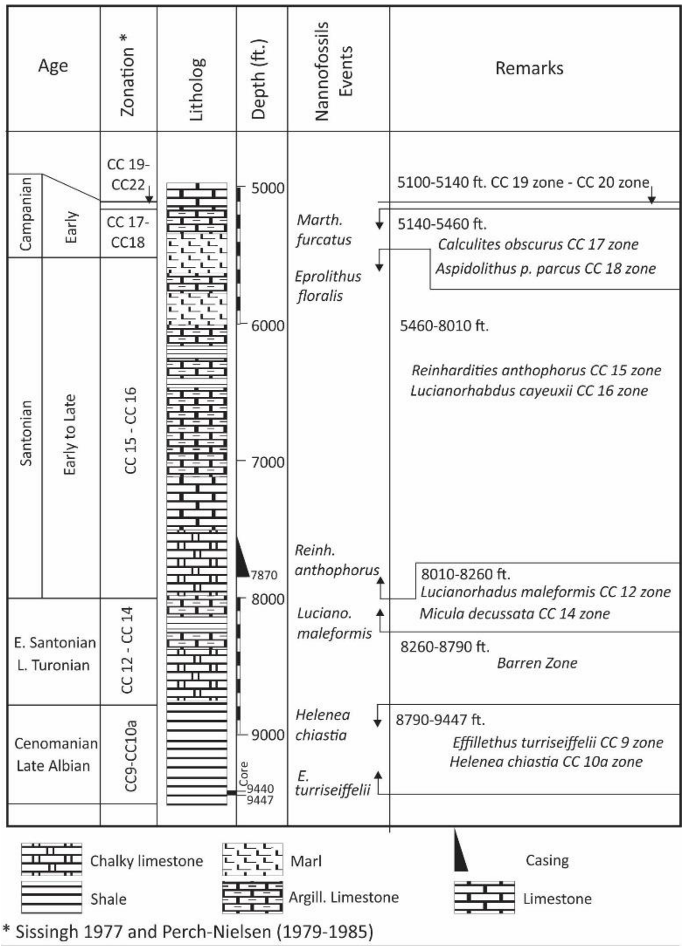


Fig. 4. Lithostratigraphy and calcareous nannofossil biozones of the studied Well E1-NC152.

3. Conclusions

In the studied Well E1-NC152 interval from 5100' to 9447', five calcareous nannofossil biozones are recognized, these are including *i) Calculites ovalis* (CC19) – *Quadrum trifidum* (CC22) (early-late Campanian); ii) *Calculites obscurus* Biozone (CC17) – *Aspidolithus parcus parcus Biozone* (CC18) late (Santonian– Early Campanian); iii) *Reinhardtites anthophorus* Biozone (CC15) - *Lucianorhabdus cayeuxii* (CC16) (Santonian according to Sissingh (1977)). However, Burnetti (1998) assigned the age to late Coniacian– early Santonian); iv) *Lucianorhabdus maleformis* Biozone (CC12) - *Micula decussata* Biozone (CC14) (middle Turonian – middle Coniacian); v) *Eiffellithus turriseiffilii* Biozone (CC9) – *Microrhabdulus decorates* Biozone (CC10a) (late Albian – Cenomanian). In addition to the studied surface outcrop, the Jardas Al Abid Formation is assigned to CC10 biozone which equivalent to UC3 (a-d). The results from these studied sections are correlated with the previously established calcareous biozones of El-Mehaghag (1996); El Mehaghag and Muftah, (1996); El Mehaghag and El Mehdawi (2006), and Starkie (2007) (Fig. 6). The studied successions of the studied Well E1-NC152 started with the Qasr al Abid Formation "Albian to Cenomanian" CC9-CC10a biozones which is equivalent to core #1 of well P1-41 as well as cores # 1 and 2 of Well A1-45 (El Mehaghag, 1996), and the uppermost part of the Biozone CC10a in the studied well is age equivalent to Qasr al Abid Formation at Jarads al Abid studied outcrop.
The *Lucianorhabdus maleformis* Biozone (CC12) - *Micula decussata* Biozone (CC14) "middle Turonian – middle Coniacian" is equivalent to core #2 of well U1-41 (El Mehaghag, 1996), and to the calcareous nannofossil biozone of the upper part of the LLC4 to LLC6 Biozones of Starkie (2007).
The *Reinhardtites anthophorus* Biozone (CC15) - *Lucianorhabdus cayeuxii* (CC16) the established calcareous nannofossil biozones in

well E1-NC152, are correlatable to core #1 of well U1-41 (El Mehaghag, 1996) and to the basal part of the Al Hila Shale (El Mehaghag and Muftah, 1996) (Fig. 8) and to the biozones LLC7- LLC8 of Starkie (2007) in wells A1-7, A1-NC129, and T1-41.
The *Calculites obscurus* Biozone (CC17) – *Aspidolithus gr. parcus Biozone* (CC18) are corresponding to core #33 of well A1-41 (El Mehaghag 1996) and to the upper part of the Al Hilal Shale (El Mehaghag and Muftah 1996), and correlatable to LLC9 - LLC10 biozones of Starkie (2007).

The *Calculites ovalis* (CC19) – *Quadrum trifidum* (CC22) are corresponding to the Athrun Formation at the Wadi al Qalah section (El Mehaghag and Muftah, 1996), while the CC22 is equivalent to the upper Athrun Formation at the Wadi al Athrun section (El Mehaghag and El Mehdawi, 2006) and are correlatable to the LLC11 to LLC14 of Starki (2007).

Biozoation (Sissingh 1977)	CC19-CC22	CC17-CC18									CC15-CC16																										CC12-CC14					CC9-CC10a												
Depth ft.	5100-5140	5140-5150	5190-5200	5200-5210	5270-5280	5300-5310	5350-5360	5400-5410	5430-5440	5440-5460	5460-5490	5490-5500	5500-5510	5530-5540	5560-5570	5570-5630	5650-5660	5680-5690	5710-5720	5740-5750	5770-5780	5810-5820	5850-5860	5910-5920	5900-5990	6090-6100	6170-6180	6240-6250	6330-6340	6410-6420	6490-6500	6570-6580	6630-6640	6710-6720	6820-6830	6890-8010	8010-8020	8070-8080	8170-8180	8250-8260	8260-8790	8790-8800	8850-8860	8950-8960	9000-9010	9100-9110	9170-9180	9220-9230	9300-9310	9370-9380	Core-9440	Core-9443	Core-9446	Core-9447
Watznaueria barnesiae	R	R	R	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	R	C	C	C	C	C	C	C	C	R	C	R	C	C	R	C	C	R	C	C		C	C	C	C	R					C			C
Aspidolithus parcus expansus	R	R	R	R	R	R	R	R	R	C	R	R	R	R	R	R	R	R	R	R		R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R				R	R	R					R			R
Aspidolithus parcus parcus	R	R	R	R	R	C	C	R	C	R	R	R	R	R	C				R		R	R	R	R	R		R		R																									
Eiffellithus turriseiffelii	R	R	C	C	R	R	R	R	R	R	R	R	R	R	C	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R		R	R	R	C	R	C		R	R	R	C	R					R			R
Tranolithus gabalos	R																																													R								
Tranolithus phacelosus	R	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	R	C	C	C	C	C	C	R	R	R	R	C	C	R	R	R	R	R	R	R		R	C	R	C	R					C			R
Prediscosphaera cretacea		R	R	R	R	R	R	R	R	C	C	C	R	R	C	C	C	C	R	R		R	C	C	C	C	C	C			R	R	R		R	R	R	R	R	R				R		R								
Nannoconus quadratus quadratus							R		R	R	R	R	R	R	R	R	C	R		R	R	R	R			R	R			R							R	R	R	R														
Reinhardtites anthophorus		R	R	C	C	C	C	C	C	C	C	C	R	R	C	C	R	R	R	R	R	R	R	R	C	C	C	C	R	R	R	R	R		R	R	R	R																
Rhagodiscus angustus		R	R					R	R	R			R	R	R	R	R	R		R				R		R	R	R			R							R						R	C	R					R			
Rhagodiscus splendens					R												R															R					R	R	R					R	R	R					R			
Lithraphidites carniolensis carniolensis		R	R	C	R	C	C	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R			R															
Gartnerago obliquum	R	R	R	R	R	R	R	R	R	R	R	R	R	R			R					R			R	R	C	R	R			R	R	R				R							R									
Calculiths ovalis										R							R				R					R	R		R																									
Eiffellithus eximius	R	C	C	C	C	C	C	C	C	C	R	R	C	C	C	C	C	R	R	R	R	C	C	R	R	R	R	R	R	R	R	R	R	R	R	R		R																
Micula decussata	C	R	R	R	R	R	R	R	R	R	R	R	R	C	R	R	R	R		R		R	R	R		R	R	R		R	R		R	R																				
Micula concavata				C			R	R	R		R	R			R							R			R					R																								
Lucianorhabdus sp.																																							R					R	R									
Lucianorhabdus cayeuxii		R	R	R	R		R	R	R	R	R	R	R	R	R		R	R	R		R	R	R	R		R	R		R		R		R	R	R																			
Eprolithus floralis											R	R			R	R		R	R	R		R	R		R		R		R	R	R	R			R	R				R			R	R	R								R	
Arkhangelskiella specillata		R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R				R		R	R	R	R	R		R	R	R	R	R	R	R				R	Barren Zone			R										
Lucianorhabdus maleformis		R	R	R	R	R	R	R	C	R	R	R	R	R	C	R	R	R	R	R			R	R	R	R	R	R	R	R		R	R	R	R					R														
Nannoconus elongatus					R		R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R			R	R			R		R	R		R							R												
Zygodiscus pseudoanthophorus																																											R	R	R	R					R			R
Helenea chiastia																																										R	R	C	R	R			C		C			
Chiastozygus amphipons			R	R			R	R	R				R		R	R	R				R		R			R	R		R															R	R	R			R					
Cribrosphaerella ehrenbergii		R	R	R	R	R	R		R	R	R	R	R	R	R	C	R	R	R	R	R	R			R	R	R	R	R	R		R			R									R										
Lithraphidites acutus																																												R							C = common			
Staurolithites baldiae																																													R						R = Rare			
Lithraphidites alatus																																													R									
Corollithion sp.																																													R									
Ahmuellerella octoradiata		R	R	R	R	R	R	R	R	R	R	R	R	R	R	R		R		R	R	R			R	R	R	R	R	R	R	R		R	R											R								
Flabellites biforaminis																																																					R	
Marthasterites furcatus		R	R	R	R	R	R	R	R		R	R	R		R	R		R				R		C	C	R	R	R	R	R	R	R	R			R																		
Orastrum campanensis		R	R	C	R		R	R	R		R	R	R	R		R		R		R		R	R	R		R	R	R	R		R				R																			
Lithastrinus grillii								R	R	R	R	R	R	R	C	R	R	R	R	R	C	C	R	R	R	C	R	C	R	R			R	R	R																			
Nannoconus truittii subsp. Rectangularis																													R	R			R																					
Quadrum gartneri																		R					R		R				R																									
Braaradosphrar bigwloi																		R					R			R																												
Quadrum gothicum																															R																							

Fig. 5. Distribution chart of calcareous nannofossils in well E1-NC152.

Taxonomy

Alphabetic listing of all genera and species identified in this paper.

Genus: *Ahmuellerella* Reinhardt 1964

A. octaradiata (Gorka, 1957) Reinhardt (1964)

Genus: *Arkhangelskiella* Vekshina 1959

A. specillata Vekshina (1959)

Genus: *Aspidolithus* Noel (1969)

A. parcus expensus (Wise and Watkins in Wise 1983)
A. parcus parcus (Strander 1963) Noel 1969

Genus: *Biscutum* Black in Black and Barnes 1959

B. ellipticum (Gorka 1957) Grun in Grun and Allemann (1975)

Genus: *Braarudosphaera* Deflandre 1947

B. bigelowii (Gran and Braarud 1935) Deflandre 1947

Genus: *Calculites* Prins and Sissingh in sissingh (1977)

C. ovalis (Stradner 1963) Prins and Sissingh in Sissingh 1977

Genus: *Chiastozygus* Gartner (1968)

C. *amphipinus* (Bramlette and Martini 1964) Gartner 1968

Genus: *Corollithion* Stradner (1961)

C. Kennedyi Crux (1981)

Genus: *CriprosphArerella* Deflandre in Piveteau (1925)

C. *ehrenbergii* (Arkhangelsky 1912) Deflandre in Pivetau 1952

Genus: *Eiffillithus* Reinhardt 1965

E. eximius (Stover 1966) Perch-Nielsen 1968
E. turriseffelii (Deflandre in Deflandre and Fert 1954) Reinhardt 1965

Genus: *Eprolithus* Stover 1966

E. floralis (Stradner 1962) Stover 1966

Genus: *Flabellites* Thierstein 1973

F. biforaminis Thierstein 1973

Genus: *Gartnerago* Bukry 1974

G. obliquum (Stradner 1963) Noel 1970

Genus: *Helenea* Worsley (1971)

H. chiastia Worsley 1971

Genus: *Lithastrinus* Strandner 1962

L. grillii Stradner 1962

Genus: *Lithraphidites* Deflandre 1963

L. carniolensis carniolensis Deflandre 1963
L. acutus Verbeek and Manivit in Manivit *et al*., (1977)

Genus: *Lucianorhabdus* Deflandre 1959

L. cayeuxii Deflandre 1959
L. maleformis Reinhardt 1966

Genus: *Marthasterites* Deflandre 1959

M. furcatus Bramlette in Deflandre 1959

Genus*: Miculs* Vekshina 1959

M. concava (Stradner 1963 in Martini and Stradner 1960) Verbeek (1976)

M. decussata Vekshina, 1959

Genus: *Nannoconus* Kamptner 1931

N. quadratus quadratus (Noel 1959) deres and cheriteguy 1980

N. truittii rectangularis Deres and Acheriteguy 1980

Genus*: Orastrum* Wind and Wise in Wise and Wind 1977

O. campanensis (Cepek 1970) Wind and Wise in Wise and Wind 1977

O. perspicuum Varol in Al-Rifaiy *et al*., 1990 Rank

Genus*: Owenia* (Crux 1992)

O. hillii Lees 2007

Genus: *Prediscosphaera* Vekshina (1959)

P. cretacea (Arkhangelsky 1912) Gartner 1968

Genus*: Quadrum* Prins and Perch-Nielsen in Manivit et al., 1977

Q. gartneri Prins and Perch-Nielsen in Manivit et al., 1977

Q. gothicum (Deflandre 1959) Prins and Perch-Nielsen in Manivit et al., 1977

Genus*: Rahagudiscus* Reinhardt 1967

R. angustus (Stradner 1963) Reinhardt 1971

R. splendens (Deflandre 1953) Verbeek 1977

Genus*: Reinhardtites* Perch-Nielsen 1968

R. anthophorus (Deflandre 1959) Perch-Nielsen 1968

Genus*: Retecapsa* Black (1971)

R. crenulata (Bramlette & Martini, 1964) Grün in Grün and Allemann, 1975

Genus: *Tegumentum* Thierstein in Roth and Thierstein 1972

T. stradneri Thierstein in Roth and Thierstein 1972

Genus*: Tranolithus* (Stover 1966)

T. gabalus (Stover 1966)

T. orionatus (Reinhardt 1966) Perch-Nielsen 1968

T. phacelosus Stover (1966)

Genus*: Watznaueria* Reinhardt 1964

W. barnesae (Black 1959 in Black and Barnes 1959) Perch-Nielsen 1968

W. manivitiae Bukry, 1973

Genus: *Zeugrhabdotus* Rienhardt (1965)

Z. noeliae Rood et al., (1971)

Z. scutula (Bergen, 1994) Rutledge & Bown, 1996 Rank

Genus*: Zygodiscus* Stover 1966

Z. pseudoanthrophorus (Bramlette and Martini 1964) Perch-Nielsen (1984)

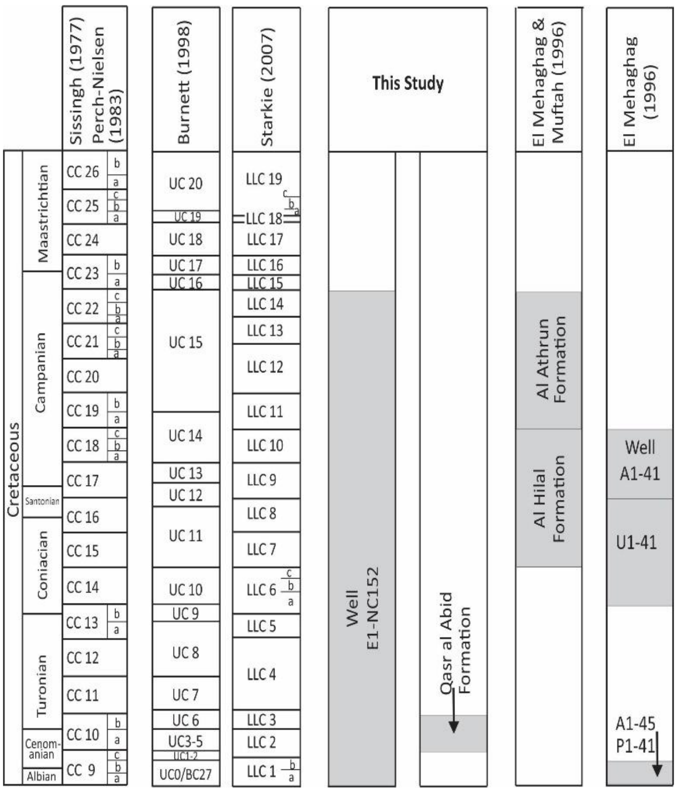


Fig. 6. Correlation chart of the calcareous nannofossils schemes against the present studied sections and selected published works

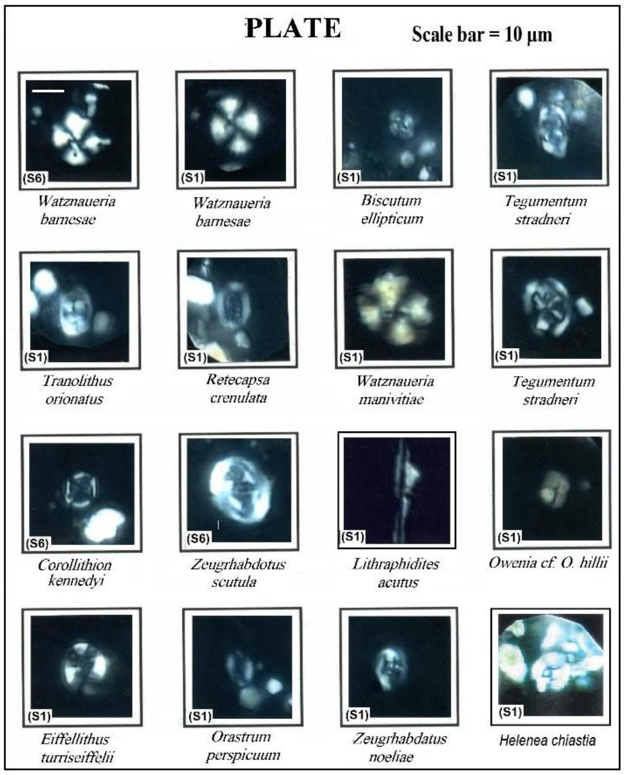


Fig. 7. Calcareous nannofossils from Jardas al Abid Formation close to Jardas School exposure. (Note: Sample no. is at the bottom left corner).

Fig. 8. Calcareous nannofossils of Al Hilal and Athrun sections (El Mehaghag and Muftah, 1996).

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