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RESEARCH PAPER

Biostratigraphy of Paleocene strata based on calcareous nannofossils at Zard-Darreh section, southern central Alborz Mountains, Northern Iran

Fariba Foroughi [1,*], Hadi Ghadim Khatoon Abad [1], Hossein Kamyabi Shadan [2]

[1] Department of Geology, Faculty of Sciences, University of Tehran, Tehran, Iran
[2] Exploration Directorate of the National Iranian Oil Company, Tehran, Iran

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Abstract
The study area is located in the Zard-Darreh village nearby Damavand city in the eastern part of Tehran province. Late Cretaceous strata are well-exposed in the Zard-Darreh village, comprising siliciclastic sediments with limestone stringers, which are overlain by red conglomerate deposits of the Fajan Formation. This study was carried out on a 96 m interval of the K3 and Fajan Formation to determine the precise age of the sampling interval. Eighty-nine surface samples were collected and treated for calcareous nannofossils. 53 species (27 genera) and 15 families were identified and nine biozones were established. Biozone CC20/UC15b^{TP} occurs in the lowermost part of the K3 and represents the Late Cretaceous (Campanian) age. The NP1 to NP8 biozones are present the rest of the study interval, suggesting Early Paleocene (Danian-Thanetian) age. Based on calcareous nannofossils the Early Paleocene is recorded for the first time in the Zard-Darreh village in the Alborz Mountains. Likewise, a hiatus exists between the Late Cretaceous (CC20/UC15b^{TP}) and Early Paleocene (NP1), which encompasses the Maastrichtian stage and part of Early Paleocene. Finally, some small size calcareous nannofossils such as *Biantholithus sparsus, Cruciplacolithus primus, Cruciplacolithus intermedius,* and *Cruciplacolithus asymmetricus* are present in the NP1 biozone of Early Paleocene, which may indicate the effect of various environmental factors. Furthermore, some calcareous nannofossils such as *Sphenolithus* spp. and *Discoaster mohleri* are present in NP6 and NP7 biozones of the study area that may indicate a warning climatic condition toward the Eocene.

Keywords: Calcareous nannofossils, central Alborz Mountains, Cretaceous, Northern Iran, Paleocene.

Introduction

The study area is called Zard-Darreh village, which locates near Damavand city in northeastern Tehran province, and in turn, it is part of the Central Alborz Mountain (Fig. 1A). The Alborz Mountains stretches from the border of Azerbaijan along the western and entire southern coast of the Caspian Sea and finally runs northeast and merges into the Aladagh Mountains in the northern parts of Khorasan province (Fig.1A). The Alborz Mountains are divided into the Western, Central, and Eastern areas that the Cretaceous and Paleocene deposits rock units extend throughout this mountain ranges. The Cretaceous deposits have not been assigned to a standard rock unit yet, whereas the Paleogene strata have standard names. However, Dellenbach (1964) suggested the stratigraphic units K1, K2a, K2b, K2c, and K3 for the Cretaceous deposits at the Sepayeh Mountain area and Steiger (1966) divided these strata into the rock units of C1, C2, C3, and C4 at Firoz-Kuh and Damavand areas, eastern Tehran province. The Zard-Darreh

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* Corresponding author e-mail: f.foroughi@ut.ac.ir

village is part of the Firoz-Kuh-Damavand areas, which the Upper Cretaceous and Paleogene strata are well-exposed and accessible for measurement and sampling. Hence, it was selected as a pilot project to study the calcareous nannofossils for the age relationships of the Cretaceous-Paleogene strata. The aims of this study are 1) determination of calcareous nannofossils at the levels of species and genera; 2) establishment of calcareous nannofossil biozones and 3) clarify age relationships of the study interval to Cretaceous *vs.* Paleogene.

Geological setting and Previous works

The Zard-Darreh village is located approximately 76 Km eastern Tehran province (Fig. 1A). In this area, the Fajan and Tiz-e Kuh formations have an exposure, which are briefly discussed in ascending stratigraphic order: The Tiz-e Kuh Formation is 170 m thick and contains detrital limestone (Assereto & Ippolito, 1964). This formation rests on the Lar Formation (Upper Jurassic), and the Fajan Formation overlies it. The upper contact of the Tiz-e Kuh Formation has angular unconformity with underlying formation (Lar Formation) and conformable contact with overlaying formation (Fajan Fm). This formation contains both macro and microfossils and its age relationship range from Upper-Lower Cretaceous (Assereto & Ippolito, 1964). Later on, this formation was assigned to Upper Cretaceous by Sadeghi, 1999 (unpublished PhD thesis) and Upper Paleocene by Ghiasi, 1993 (unpublished MSC thesis) in the southern Alborz Mountains. The Fajan Formation was named after the Fajan village, which is located 100 km eastern Tehran city. This formation has a thickness of 1500 m at the type section (Fajan village) and it consists of polymictic conglomerates, red sandstone, and sandy marls intercalated with Andesite and agglomerate deposits (Dellenbach, 1964). The Fajan Formation does not contain any fossils in its type locality. Therefore, based on its stratigraphic position with the Ziarat Formation (Lower Eocene), assigning to the Paleocene-Lower Eocene (Dellenbach, 1964). The Fajan Formation has a thickness of 1500 m at the type locality village of Fajan, east of Tehran (Dellenbach, 1964), but its consistency is restricted to a few meters in the Zard-Darreh village and overlain by the Ziarat Formation. The Ziarat Formation contains abundant foraminiferal with Early to Middle Eocene age. Therefore, based on the stratigraphic position, the Fajan Formation has been assigned to the Paleocene-Lower Eocene age (Allenbach, 1966).

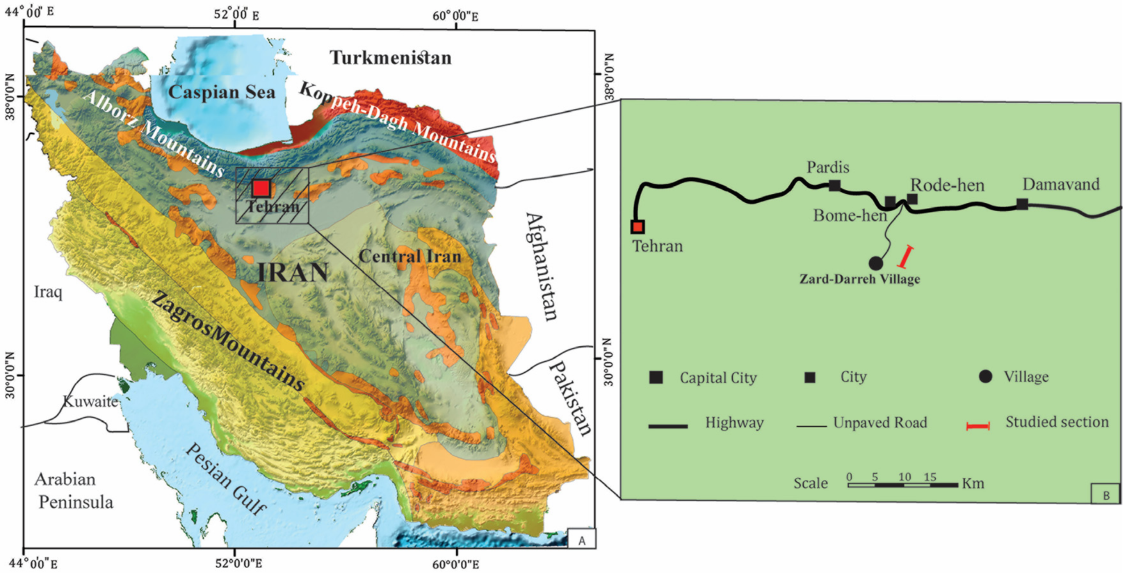

Figure 1. Location map of the study area (1. A) and connection to adjacent cities (1. B) southern central Alborz Mountains, Northern Iran

According to Dellenbach (1964), the thickness of the Fajan Formation reduces rapidly until a few-meter conglomerate. At the same time, the overlying foraminiferal limestone of the Middle Eocene in the Fajan area includes older stages down to the Paleocene in the area. There are conglomerate deposits in other parts of the Iranian platform that are closely comparable in stratigraphic position with the Fajan Formation. Therefore, these changes appear not only in the Alborz Mountains but also in Central and Eastern Iran. The conglomerate deposits are a key, which fills Late Cretaceous-Paleocene relief. Because of lateral interfingering with the Ziarat and Fajan formations. The Fajan Formation seems comparable with some of the various conglomerate deposits in eastern and central Iran, which have collectively been called "Kerman Conglomerate" and correspond to the "Pesteligh Red Beds" in the Koppeh-Dagh region (Stöcklin & Setudehnia, 1971). Hence, the Paleogene strata are present through the Alborz Mountains, Kopeh-Dagh region, and Central Iran. This study aims to determine the relative age of study interval strata based on calcareous nannofossils. It should be mentioned, that the Paleogene strata are registered for the first time in the Alborz Mountains by using calcareous nannofossils.

Materials and Methods

The study section comprises grey-green and yellow-red calcareous silty shales and argillaceous limestones, which have been assigned to the Late Cretaceous age (Figs. 2; 3). Likewise, the Cretaceous strata are overlain by the polymictic conglomerate of the Fajan Formation (Stöcklin & Setudehnia, 1971). This stratigraphic interval is 96 m thick, and 89 surface samples were systematically collected and treated in the Geological Department of Tehran University laboratory. The coordination of the study area is 51° 53' 31" E longitudes and 35°36' 52.1" N latitudes (Fig. 1B). The samples were treated using the gravity settling technique of Bown (1998). In this study, the stratigraphic potential of each species was considered by the First Occurrence (FO) and the Last Occurrence (LO) that they plotted on Fig. 4 and illustrated in plates (I, II). Likewise, some thin sections were prepared to study the foraminifer entities of underling (K3) and overlying (Fajan and Ziarat formations).

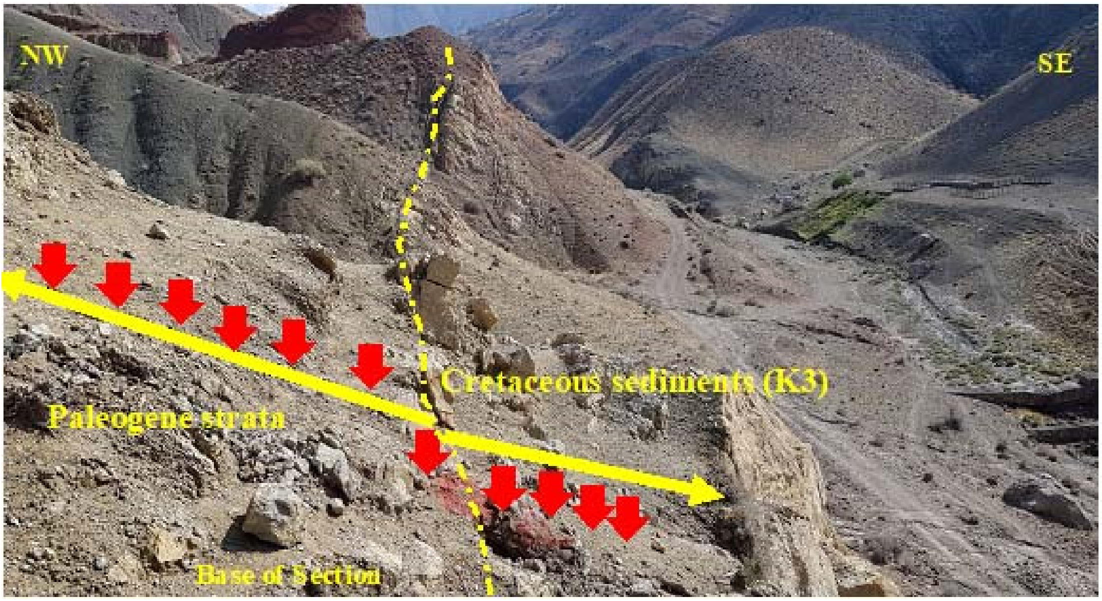

Figure 2. Geological outcrop of the study area and illustration contact of Paleocene and Cretaceous boundary, in the Zard-Darreh village, southern central Alborz Mountains, Northern Iran

Figure 3. Geological outcrop of study interval and its contact with the Fajan Formation in the Zard-Darreh village, southern central Alborz Mountains, Northern Iran

All samples contain calcareous nannofossils by using the visual criteria concerning the degree of etching and overgrowth (Roth, 1973; Watkins, 2007). Nannofossils were analyzed using an Axioskop Imaging 40 Pol Zeiss Light Microscope (LM) at a magnification of X1000. All photographic images were taken in either cross-polarized light (XPL) or normal light (BF). The encountered nannofossils have fairly Moderate (M) to Poor (P) preservation and are counted semi-qualitatively for all specimens. The counts were presented as the followings: abundant (A) where the number of specimens is > 10 which are observed in a FOV (= Field of view); common (C) is used where 1-10 specimens were observed in a FOV; few (F) where one specimen was observed in 10 FOVs; rare (R) where only one specimen was observed in 11-100 FOVs.

Biostratigraphy results

Several Cenozoic calcareous nannofossil biozonations have been established over the past four decades (e.g., Martini, 1971, 1976; Bukry, 1973, 1975, 1978; Stow et al. 2013) and individual biostratigraphers (Toffanin et al., 2013). Backman et al. (2012) made a major revision of the Miocene through Pleistocene calcareous nannofossil biozonations and he stated that these biozonations introduce a consistent result, but other biozonations cannot be reliable (Agnini et al., 2014). Herein, we used Martini's biozonation for the study interval of the Zard-Darreh village in the Alborz Mountains. In this study, 53 species (27 genera) and 15 families of calcareous nannofossils were identified and some of the index taxa plotted on Plates (I, II), Fig. 4 and Table 1. Based on the FO and LO of identified calcareous nannofossils nine biozones were established which are discussed below:

(Pro Parte) Ceratolithoides aculeus Zone (CC20/UC15b^{TP})

This biozone is characterized by the first occurrence (FO) of *Ceratolithoides aculeus* to the FO of *Uniplanarius sissinghii* and it shows the late Early Campanian age. The youngest key of Cretaceous calcareous nannofossils of these strata except *Ceratolithoides aculeus* was not found in the interval study.

So far, *Ceratolithoides aculeus* has been recorded from the Late Cretaceous (Campanian) elsewhere: Campanian, W. Indian Ocean, (Müller, 1974); Campanian, Tunisia (Sissingh, 1977); middle Campanian, USA (Hattner & Wise, 1980); Campanian, Indian Ocean (Burnett, 1998); Campanian, N. Pacific (Lees & Bown, 2005); Campanian, USA (Stradner, 2010).

This species is associated with other Late Cretaceous species such as *Broinsonia parca constricta, Arkhangelskiella cymbiformis, Prediscosphaera cretacea, Micula decussata, Eiffelithus eximius, Microrhabdulinus ambiguus* (curve spine), and *Watznaueria barnesiae* based on Perch-Nielsen, 1985; Burnett, 1998; Bown, 1998 studies. This biozone is the base of interval study through a thickness of 1 m (samples HGZ1-HGZ4) and youngest keys of calcareous nannofossils are *Ceratolithoides aculeus* and *Microrhabdulinus ambiguus*. The calcareous nannofossil species from the Maastrichtian age does not present in this interval.

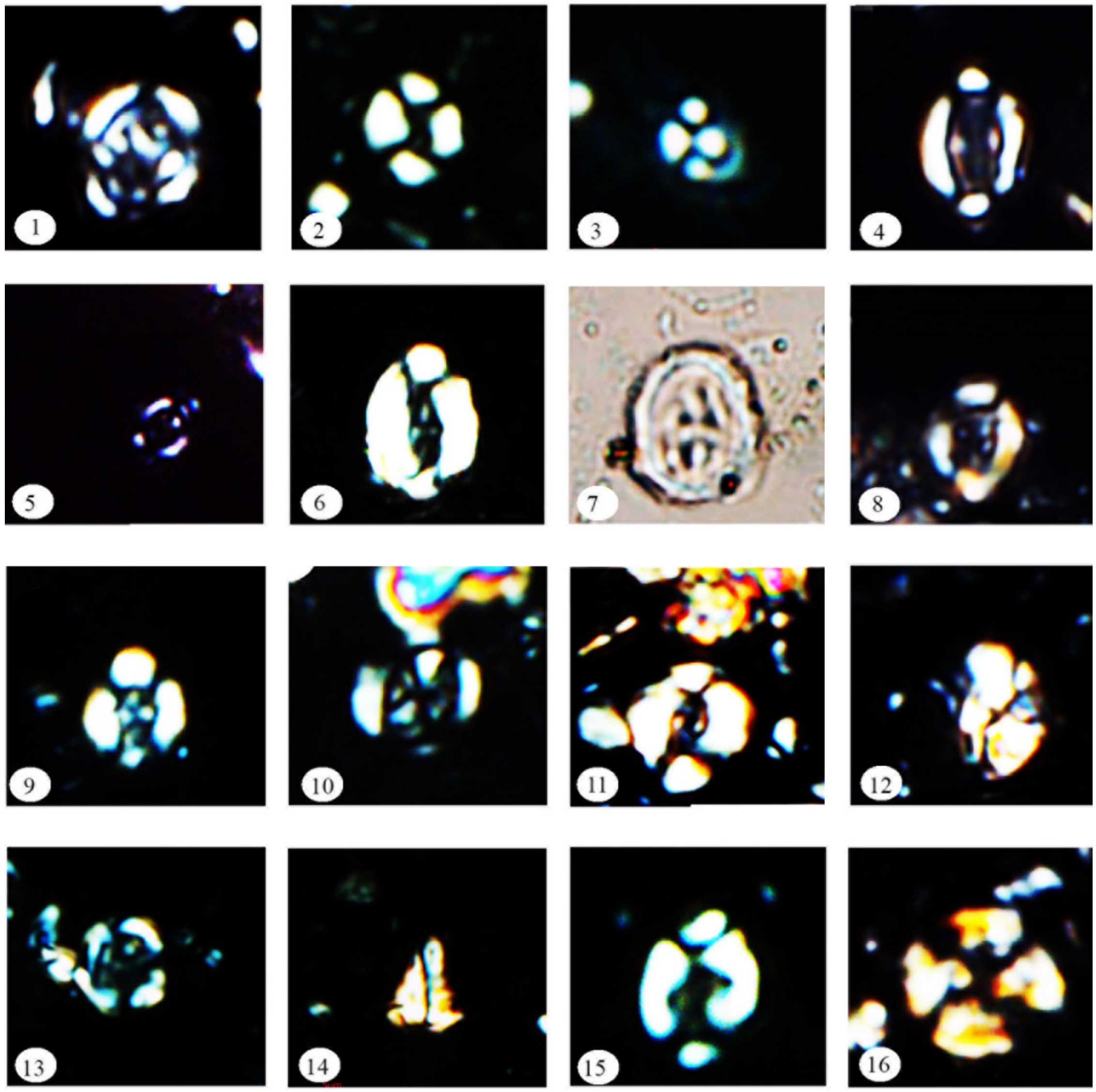

Plate I. The pictures of calcareous nannofossil of interval study: Cross-Polarized Light (XPL) and Normal Light (PPL). The scale bar is 5μm. 1. *Chiasmolithus bidens,* (XPL); 2. *Coccolithus plagicus,* (XPL); 3. *Prinsius martinii,* (XPL); 4. *Cruciplacolithus neohelis,* (XPL); 5. *Cruciplacolithus primus,* (XPL); 6 (XPL), 7 (PPL). *Cruciplacolithus intermedius*; 8. *Cruciplacolithus tenuis,* (XPL); 9. *Cruciplacolithus edwardesii,* (XPL); 10. *Cruciplacolithus latipons,* (XPL); 11. *Cruciplacolithus frequens,* (XPL); 12. *Ellipsolithus macellus,* (XPL); 13. *Chiasmolithus danicus,* (XPL); 14. *Zygrhablithus bijugatus,* (XPL); 15. *Zygodiscus sheldoniae,* (XPL); 16. *Heliolithus kleinpellii,* (XPL)

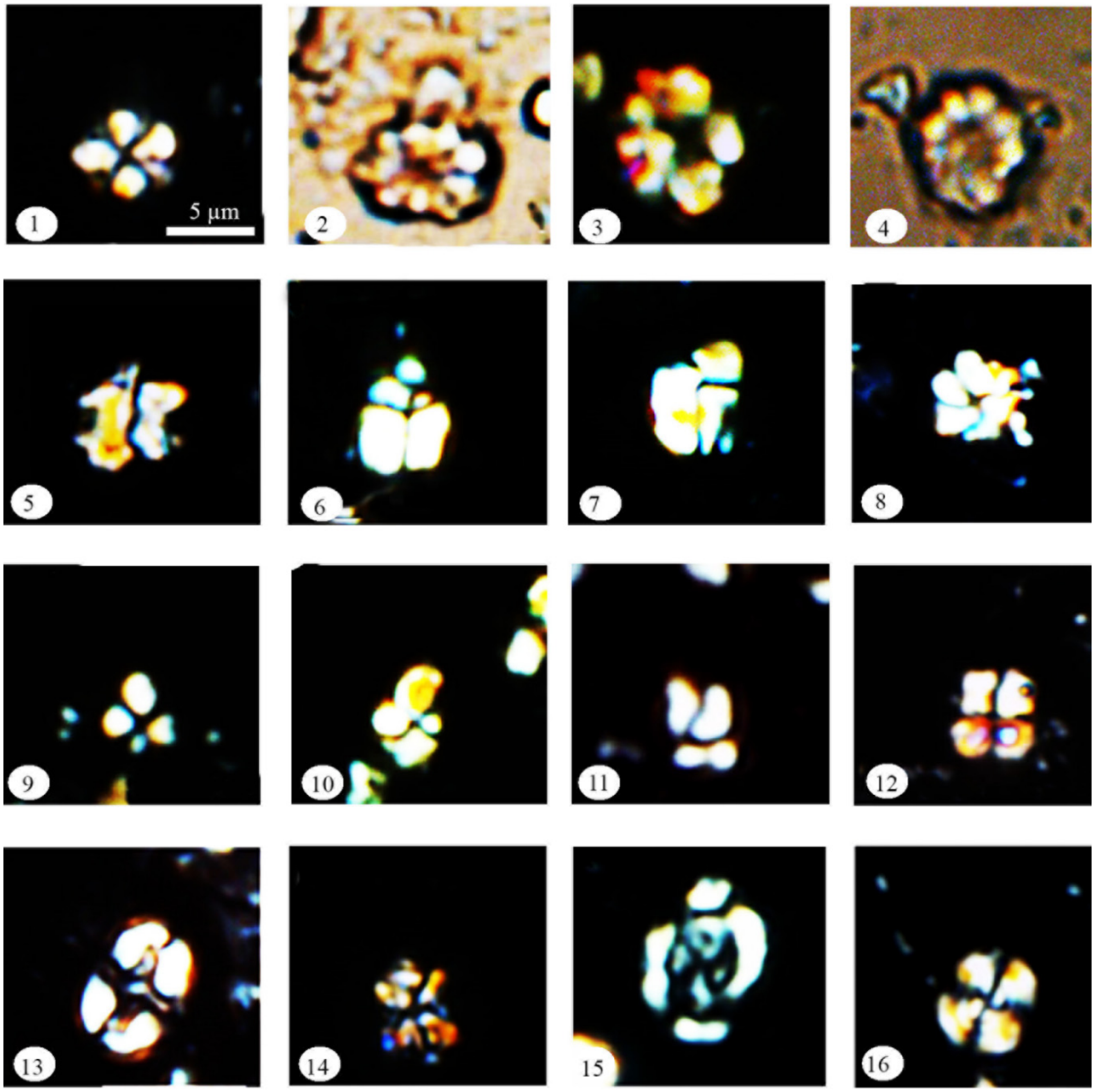

Plate II. The pictures of calcareous nannofossil of interval study: Cross-Polarized Light (XPL) and Normal Light (PPL). The scale bar is 5μm. 1, 3 & 8. *Biantholithus sparsus*, (XPL); 2 & 4, *Biantholithus sparsus*, (PPL); 5. *Fasciculithus involutus* (XPL)*; 6, 7. Fasciculithus tympaniformis,* (XPL); 9, 10, 11. *Sphenolithus anarrhopus,* (XPL); 12. *Sphenolithus moriformis,* (XPL); 13. *Eiffellithus eximius,* (XPL)*;* 14. *Micula decussata,* (XPL)*;* 15. *Arkhangelskiella cymbiformis,* (XPL); 16. *Watznaueria barnesiae,* (XPL)

(Pro Parte) Markalius inversus Zone (NP1)

This biozone is characterized by LO of Cretaceous calcareous nannofossil forms or acme zone of *Thoracosphaera operculata* and *Micula decussata* or *Biantholithus sparsus* (Perch-Nielsen, 1998b). Based on this biozone occur in the lowermost part of the study interval that continues through a thickness of 2.3 m (samples HGZ5- HGZ10) with rare (R) to few (C) frequencies of *Micula decussata* and *Biantholithus sparsus* (Fig. 4; Table 1).

The accompanied calcareous nannofossil species of this biozone are *Biantholithus sparsus*, *Markalius inversus, Cruciplacolithus primus, Cruciplacolithus intermedius,* and *Cruciplacolithus asymmetricus*.

The above-mentioned, accompanied calcareous nannofossils have been recorded from elsewhere that they are discussed below:

Up to now, *Biantholithus sparsus* has been recorded from Early Paleocene strata many localities: Early Paleocene (Danian, NP2), Tunisia (Okada & Thierstein, 1979); Late Maastrichtian, Weddell Sea, Leg 113 (Pospichal & Wise, 1990a); Early Paleocene (Danian), Weddell Sea, Leg 113 (Pospichal & Wise, 1990a); Late Paleocene (NP4), USA (Bybell & Self-Trail, 1995); Early Paleocene (NP1, Danian), Netherland (Romein et al., 1996; Mai, 1997); Upper Campanian-Maastrichtian, Denmark (Thibault, 2010).

Up to now, *Markalius inversus* has been recorded from Upper Cretaceous (UC14 biozone) to Cenozoic (NP21) strata in many localities: Danian, Denmark (Perch-Nielsen, 1969); NP14, N. Atlantic (Müller, 1979); NP9 (Late Paleocene), USA (Bybell & Self-Trail, 1995); NP1 (Danian), France (Mai et al., 1997); NW. Atlantic, M. Eocene (Bown et al. 2014). Hence, this species has reported from the Maastrichtian stage and continued to the Danian.

Cruciplacolithus intermedius has so far been recorded from the Paleocene nannofossil biozones of NP3 and NP6, Atlantic (Perch-Nielsen, 1977); Paleocene (NP6), Atlantic (Perch-Nielsen, 1977); Early Paleocene (NP3), S. Atlantic, ODP 356 (Perch-Nielsen, 1977); Early Paleocene (NP2), NW. Atlantic, ODP 348 (Okada & Thierstein, 1979); Danian, Elles Tunisia (van Heck & Paris, 1987); Early Paleocene (Danian, NP5), Tanzania (Bown, 2016) and Early Paleocene (Danian), Elles Tunisia (Thibault et al., 2018).

Cruciplacolithus asymmetricus has been recorded from Early Paleocene (Danian), *Weddell Sea*, Southern Ocean, Leg 113 (Pospichal & Wise, 1990a); Early Paleocene (Eocene, NP14B-NP15A), Tanzania (Bown, 2005), and Eocene (NP17), Tanzania (Bown, 2005).

Cruciplacolithus primus has been recorded from Early Paleocene (NP1), Netherland (Romain et al., 1996); Early Paleocene (NP3), S. Atlantic (Perch-Nielsen, 1977); Early Paleocene (NP5), S. Atlantic, DSDP 39 (Mai et., 1977); Early Paleocene (NP1), Netherland (Mai et al., 1997, 2001); Early Paleocene (NP1), El Kef, Tunisia (Burnett, 1998); Early Paleocene (NP5), S. Atlantic (Mai et al., 1998); Early Paleocene (NP9B & NP10), Tanzania (Bown, 2005); Eocene (NP21), Tanzania (Dankly Jones et al., 2009); Middle Eocene, Tanzania (Bown et al., 2014) and Early Paleocene (NP10), Tanzania (Bown, 2016). Therefore, not only *Biantholithus sparsus* but also, associated species are restricted to the Early Paleocene.

Furthermore, it should be mentioned that some calcareous nannofossil species are long-ranging, extending from Cretaceous into the Paleocene maybe there are reworked (e.g.) *Eiffelithus turriseiffelii, Watznaueria barnesiae, Arkhangelskiella cymbiformis, Broinsonia parca constricta, Eiffelithus eximius, Ceratolithoides aculeus, Micula decussata, Microrhabdulinus ambiguus* and *Prediscosphaera cretacea.*

The calcareous nannofossils of the study interval of the Zard-Dareh village indicate the early Paleocene (Danian) age or a part of (Pro Parte) NP1 biozone. Some authors believe that several Cretaceous calcareous nannofossils in low to middle latitudes can pass through the K/Pg boundary, such as *Micula decussata, Braarudosphaera bigelowii,* and *Thoracosphaera operculata* (Perch-Nielsen, 1985; Gardin & Monechi, 1998; Gardin, 2002; Bown, 2005b) that the K/Pg boundary is determined by their acme zones. In this study, *Thoracosphaera operculata* and *Braarudosphaera bigelowii* are not present to identify the K/Pg interval that may indicate the absence of a part of (Pro Parte) NP1 in this interval.

Cruciplacolithus tenuis Zone (NP2)

This biozone is marked at its base by the first occurrence (FO) of *Cruciplacolithus tenuis* to the first occurrence (FO) of *Chiasmolithus danicus* at its up. This biozone extends through a thickness of 3.2 m (samples HGZ 11- HGZ 16) with common (C) to abundant frequencies of *Cruciplacolithus tenuis* (Fig. 4, Table 1).

Up to now, *Cruciplacolithus tenuis* has been recorded from Early Paleocene (NP7), N.

Atlantic (Perch-Nielsen, 1972); Early Paleocene (Danian), W. Indian Ocean (Müller, 1978); Early Paleocene (Danian), NW. Atlantic (Okada & Thierstein, 1979); Early Paleocene (Danian), Weddell Sea, Leg 113 (Pospichal & Wise, 1990a); Early Paleocene (Danian), Asteria (Stradner et al., 2010) and Early Paleocene (Danian, NP2), Tanzania (Bown et al., 2014).

Likewise, *Prinsius dimorphosus* is present *i*n this interval that has been recorded from Early Paleocene elsewhere (e.g.,) Early Paleocene (NP4), N. Atlantic (Perch-Nielsen, 1972); Paleocene (NP1), S. Atlantic, DSDP 39 (Mai et al., 1977); Early Paleocene (Danian), Leg 113 (Pospichal & Wise, 1990a); Paleocene (NP2), S. Atlantic, DSDP 39 (Mai et al., 1998); Paleocene (NP1), Netherland (Mai, 2001); Paleocene (NP4), N. Atlantic (Perch-Nielsen, 1972); Paleocene (NP3), S. Atlantic (Perch-Nielsen, 1977); Early Paleocene (NP1), El Kef, Tunisia (Burnett, 1998); Early Paleocene (Selandian, CP4), Leg 113 (Pospichal & Wise, 1990a); Early Paleocene (NP3-NP4), NW. Atlantic (Okada & Thierstein, 1979); Paleocene (NP1), Netherland (Mai et al., 1997); Early Paleocene (NP1), S. Atlantic (Mai et al., 1998). Therefore, *Cruciplacolithus tenuis* reveals Early Paleocene for this thickness of study interval.

Chiasmolithus danicus Zone (NP3)

This biozone is marked by the first occurrence (FO) *Chiasmolithus danicus* to the first occurrence (FO) of *Ellipsolithus macellus,* which are the index species of the succeeding biozone. This biozone extends through a thickness of 2.8 m (samples HGZ 17- HGZ 20) with common (C) to abundant (A) frequencies of *Chiasmolithus danicus* (Fig. 4, Table 1).

The *Chiasmolithus danicus* has up to now been recorded from Paleocene (NP3**)**, S. Atlantic (Perch-Nielsen, 1977**)**; Paleocene (NP3**)**, NW. Atlantic **(**Okada & Thierstein, 1979); Danian (CP2), Southern Ocean **(**Pospichal & Wise, 1990a**)**; Danian, Denmark **(**Perch-Nielsen, 1969**)**; Danian (CP3**)**, Southern Ocean **(**Pospichal & Wise, 1990a) and Paleocene (NP5**)**, Tanzania (Bown, 2016**)**. In this biozone are present specimens of *Neochiastozygus* spp. (*Neochiastozygus perfectus* and *Neochiastozygus modestus*). *Neochiastozygus* spp. has been recorded from Paleocene (NP12 & NP13), USA (Bramlette & Sullivan, 1961); Danian, USA (Bramlette & Martini, 1964); Paleocene (NP9), N. Atlantic (Perch-Nielsen, 1971a); Paleocene (NP3 & NP4), S. Atlantic (Perch-Nielsen, 1977) and Paleocene (low NP1), El Kef, Tunisia (Burnett, 1998). Therefore, this biozone suggests the Early Paleocene (Late Danian) age for this thickness of study interval.

Ellipsolithus macellus Zone (NP4)

This biozone is characterized by the first occurrence (FO) of *Ellipsolithus macellus* to the first occurrence (FO) of *Fasciculithus tympaniformis,* which is the index species of the succeeding biozone. This biozone extends through a thickness of 11 m (samples HGZ 21- HGZ 35) with few (F) to common (C) frequencies of *Ellipsolithus macellus* (Fig. 4, Table 1).

Up to now, *Ellipsolithus* has been recorded from Paleocene (NP7 & NP10), USA (Bramlette & Sullivan, 1961); Paleocene (NP8), W. Indian Ocean (Müller, 1974); Paleocene (NP8), Eq. Atlantic (Perch-Nielsen, 1977); Paleocene (NP9), Paleocene (NP6), Eq. Atlantic (Perch-Nielsen, 1977); Paleocene (NP9), N. Atlantic (Müller, 1979); Paleocene (NP4, NP6, NP7 & NP9), NW. Atlantic (Okada & Thierstein, 1979); Early to Late Eocene (NP9 & NP11), USA (Bybell & Self-Trail, 1995); Paleocene (NP10), Island (Bybell & Self-Trail, 1998); Paleocene (NP10), Tanzania (Bown, 2005); Paleocene (NP4), French Pyrenees (Steurbaut & Sztrakos, 2008); Paleocene (NP9), Tanzania (Bown, 2010); Early Eocene (NP11), Maryland USA (Self-Trail, 2011); Paleocene (mid NP12), Denmark (Steurbaut, 2011); Paleocene (NP12), Belgium (Steurbaut, 2011); Paleocene (NP12 & NP13), E. Eq Pacific (Bown & Dunkley Jones, 2012) and Paleocene (NP5), Tanzania (Bown, 2016).

Likewise, *Fasciculithus involutus* is present in the upper part of this biozone. Up to now, *Fasciculithus involutus* has been recorded from Paleocene (NP7-NP8-NP9), USA (Bramlette & Sullivan, 1961); Paleocene (NP7 & NP9), N. Atlantic (Perch-Nielsen, 1971a); Paleocene (NP7, NP8), Falkland S. Atlantic (Wise & Wind, 1977); Late Paleocene, France (Wise & Wind, 1977); Late Paleocene (NP9), Falkland S. Atlantic (Wise & Wind, 1977); Paleocene (NP7, NP8), Falkland Plateau S. Atlantic (Wise & Wind, 1977); Late Paleocene, S. Atlantic (Wise & Wind, 1977); Paleocene (NP7, NP8), Falkland S. Atlantic (Wise & Wind, 1977); Late Paleocene, California (Wise & Wind, 1977); Thanetian (CP8), Southern Ocean (Pospichal & Wise, 1990b); Late Paleocene (NP9), USA (Bybell & Self-Trail, 1995); Late Paleocene (NP9), USA (Bybell & Self-Trail, 1995); Early Eocene (NP10), USA (Bybell & Self-Trail, 1995); Paleocene (NP8), Belgium (Steurbaut, 1998); Paleocene (NP9), Tanzania (Bown, 2005); Paleocene (NP4), French Pyrenees (Steurbaut & Sztrakos, 2008); Paleocene (NP9), Tanzanian (Bown, 2010); Late Paleocene (NP9), Maryland USA (Self-Trail, 2011); Early Eocene (NP10), Maryland USA (Self-Trail, 2011); Paleocene (NP9), USA (Self-Trail et al., 2012); Early Eocene (NP10), New Zealand (Shepherd & Kulhanek, 2016) and Paleocene (NP4, NP6, NP7), Tanzania (Bown, 2016). As the result, the *Ellipsolithus macellus* indicate the Early Paleocene (Late Danian).

Fasciculithus tympaniformis Zone (NP5)

This biozone is highlighted by the first occurrence (FO) of *Fasciculithus tympaniformis* to the first occurrence (FO) of *Heliolithus kleinpellii* which are present through a thickness of 10.2 m (samples HGZ 36- HGZ 47) with few (F) to common (C) frequencies of *Fasciculithus tympaniformis* (Fig. 4, Table 1).

Up to now, *Fasciculithus tympaniformis* has been recorded from Paleocene (NP7), N. Atlantic (Perch-Nielsen, 1971a); Paleocene (NP6-NP9), W. Indian Ocean (Müller, 1974); Paleocene (NP7-NP8), Eq. Atlantic (Perch-Nielsen, 1977); Paleocene (NP6-NP7), NW. Atlantic (Okada & Thierstein, 1979); Danian (CP2), S. Ocean (Pospichal & Wise, 1990b); Ypresian (CP10-11), S. Ocean (Pospichal & Wise, 1990b); Paleocene (NP7), NW. Atlantic (Okada & Thierstein, 1979); Selandian (CP4), S. Ocean (Pospichal & Wise, 1990b); Thanetian (CP8), S. Ocean (Pospichal & Wise, 1990b); Late Paleocene (NP9), USA (Bybell & Self-Trail, 1995); Paleocene (NP9), Tanzania (Bown, 2005); Paleocene (NP5), French Pyrenees (Steurbaut & Sztrakos, 2008); Paleocene (NP9), USA (Self-Trail et al., 2012); Paleocene (NP5- NP7), Tanzania (Bown, 2016) and Paleocene (NP10), New Zealand (Shepherd & Kulhanek, 2016).

Therefore, not only *Fasciculithus tympaniformis,* but also, associated species are restricted to the Early Paleocene (Selandian-Thanetian) age.

Heliolithus kleinpellii Zone (NP6)

This biozone is marked by the first occurrence (FO) of *Heliolithus kleinpellii* to the first occurrence (FO) of *Discoaster mohleri* of the succeeding zone. This biozone extends through a thickness of 34.5 m (samples HGZ 48- HGZ 73) with a few (F) frequencies of *Heliolithus kleinpellii* (Fig. 4, Table 1).

Heliolithus kleinpellii has up to now been recorded from Paleocene (NP7), Eq. Atlantic (Perch-Nielsen, 1971b); Paleocene (NP6), N. Atlantic (Perch-Nielsen, 1971a); Paleocene (NP6), W. Indian Ocean (Müller, 1974); Late Paleocene, France (Wise & Wind, 1977); Paleocene (NP6), NW. Atlantic (Okada & Thierstein, 1979); Paleocene (NP6), SW Atlantic Ocean (Wei, 1988); Thanetian (CP5), Southern Ocean (Pospichal & Wise, 1990b); Paleocene (NP6), Maaseik (Steurbaut, 1998) and Paleocene (NP6 & NP7), Tanzania (Bown, 2016).

Therefore, the *Heliolithus kleinpellii* and associated species are appeared in this biozone and were restricted to the Early Paleocene (Selandian-Thanetian) age for study interval.

Discoaster mohleri Zone (NP7)

This biozone is highlighted by the first occurrence (FO) of *Discoaster mohleri* to the first occurrence (FO) of Heliolith*us riedelii.* This zone immediately occurs above NP6 and extends through a thickness of 16 m (samples HGZ 74- HGZ 80) of the study interval with a rare (R) frequency of *Discoaster mohleri* (Fig. 4, Table 1).

Discoaster mohleri has up to now been recorded from Paleocene (NP8), W. Indian Ocean (Müller, 1974); Paleocene (NP7 & NP8), Eq. Atlantic (Perch-Nielsen, 1977); Paleocene (NP7 & NP8), NW. Atlantic (Okada & Thierstein, 1979); Paleocene (NP8, NP12 & NP13), Israel (Theodoridis, 1984); Paleocene (NP9, NP10), USA (Bybell & Self-Trail, 1995); Paleocene (upper NP8), Belgium (Steurbaut, 1998); Paleocene (NP7), NE. France (Steurbaut, 1998); Paleocene (NP9), Tanzania (Bown, 2005); Paleocene (NP10), USA (Bralower & Self-Trail, 2016) and Paleocene (NP7), Tanzania (Bown, 2016). Likewise, the *Discoaster mohleri* species has appeared in this biozone and it is restricted to the Early Paleocene (Selandian-Thanetian) age.

Heliolithus riedelii Zone (NP8)

This biozone is characterized by the FO *Heliolithus riedelii* which continues to the basal part of the Fajan Formation. This biozone is the youngest in the study interval and includes a thickness of 15 m (samples HGZ 81- HGZ 90) of the study interval with a rare (R) frequency of *Heliolithus riedelii* (Fig. 4, Table 1). The associated calcareous nannofossils in this biozone are restricted to *Sphenolithus* sp.

Up to now, *Heliolithus riedelii* has been recorded from Paleocene (NP7 & NP9), N. Atlantic (Perch-Nielsen, 1971a); Late Paleocene, California (Wise & Wind, 1977); Paleocene (NP8 & NP9), NW Atlantic (Okada & Thierstein, 1979); Paleocene (upper NP8), Belgium (Steurbaut, 1998) and Thanetian (CP7), Southern Ocean (Pospichal & Wise, 1990b). Based on the stratigraphic distribution of these two species, the upper part of the study interval is assigned to the Late Paleocene (Selandian-Thanetian). The brief distribution of biozones in the study interval has shown in Table 1.

Table 1. The brief distribution of biozones in the study interval

Interval study Biozones	Description of biozones	Thickness (m)	Sample nos.	Age
NP8	FO *Heliolithus riedelii* to FO *Discoaster multiradiatus*	15	HGZ 81-HGZ 90	Selandian-Thanetian
NP7	FO *Discoaster mohleri to* FO *Heliolithus riedelii*	16	HGZ 74-HGZ 80	Selandian-Thanetian
NP6	FO *Heliolithus kleinpellii* to FO *Discoaster mohleri*	34.5	HGZ 48-HGZ 73	Selandian-Thanetian
NP5	FO *Fasciculithus tympaniformis* to FO *Heliolithus kleinpellii*	10.2	HGZ 36-HGZ 47	Selandian-Thanetian
NP4	FO *Ellipsolithus macellus* to FO *Fasciculithus tympaniformis*	11	HGZ 21-HGZ 35	Late Danian
NP3	FO *Chiasmolithus danicus* to FO *Ellipsolithus macellus*	2.8	HGZ 17-HGZ 20	Late Danian
NP2	FO Cruciplacolithus *tenuis* to FO *Chiasmolithus danicus*	3.2	HGZ 11-HGZ 16	Early Danian
Pro Parte NP1	Pro Parte LO Cretaceous taxa to FO *Cruciplacolithus tenuis*	2.3	HGZ 5-HGZ 10	Early Danian
Pro Parte CC20/UC15b^{TP}	Pro Parte FO *Ceratolithoides aculeous* to *Uniplanarius sissinghii*	1	HGZ 1-HGZ 4	Late Cretaceous (Campanian)

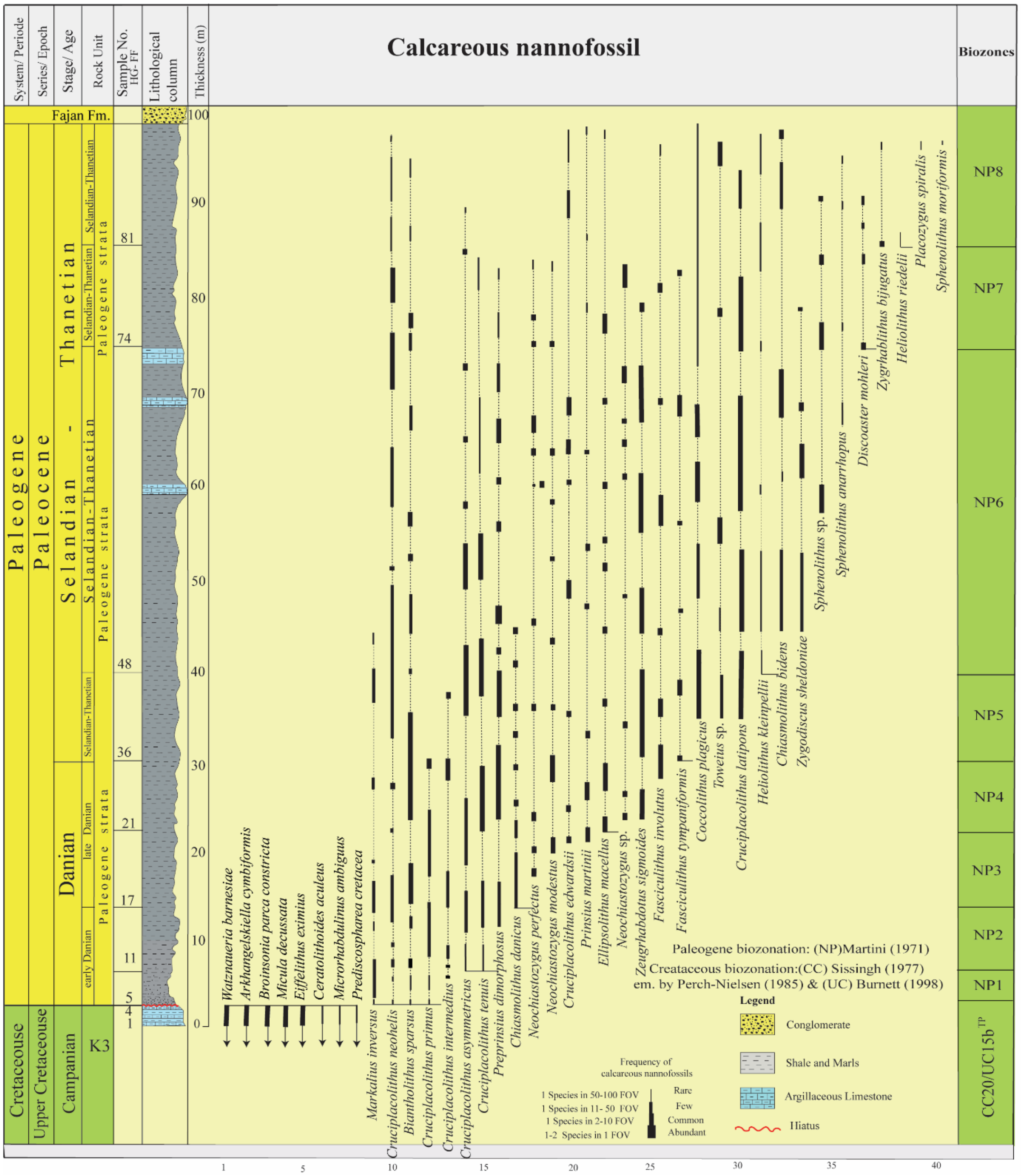

Figure 4. Stratigraphic distribution of identified calcareous nannofossil taxa within the uppermost Cretaceous and study interval strata in the Zard-Darreh village (numbers refer to taxa listed in the caption. 1. *Watznaueria barnesiae*; 2. *Arkhangelskiella cymbiformis*; 3. *Broinsonia parca constricta*; 4. *Micula decussata*; 5. *Eiffelithus eximius*; 6. *Ceratolithoides aculeus*; 7. *Microrhabdulinus ambiguus;* 8. *Prediscosphaera cretacea*; 9. *Markalius inversus*; 10. *Cruciplacolithus neohelis*; 11. *Biantholithus sparsus*; 12. *Cruciplacolithus primus*; 13. *Cruciplacolithus intermedius*; 14. *Cruciplacolithus asymmetricus*; 15. *Cruciplacolithus tenuis*; 16. *Preprinsius dimorphosus*; 17. *Chiasmolithus danicus*; 18. *Neochiastozygus perfectus*; 19. *Neochiastozygus modestus*; 20. *Crusiplacolithus edwardesii*; 21. *Prinsius martini*; 22. *Ellipsolithus macellus*; 23. *Neochiastozygus* sp.; 24. *Zeugrhabdotus sigmoides*; 25. *Fasicolithus involutus*; 26. *Fasciculithus tympaniformis*; 27. *Coccolithus plagicus*; 26. *Toweius* sp.; 29. *Cruciplacolithus latipons*; 30. *Heliolithus kleinpellii*; 31. *Chiasmolithus bidens*; 32. *Zygodiscus sheldoniae*; 33. *Sphenolithus* sp.; 34. *Sphenolithus anarrhopus*; 35. *Discoaster mohleri*; 36. *Zygrhablithus bijugatus*; 37. *Heliolithus riedelii*; 38. *Placozygus spiralis*; 39. *Sphenolithus moriformis*

Sphenolithus sp. has been recorded from Late Eocene, USA (Gartner, 1971); Miocene (NN4 & NN5), N. Atlantic (Perch-Nielsen, 1972); Oligocene (NP23), N. Atlantic (Perch-Nielsen, 1972); Eocene (NP13 & NP14), N. Atlantic (Perch-Nielsen, 1972); Paleocene (NP22), S. Atlantic (Perch-Nielsen, 1977); Paleocene (NP16), S. Atlantic (Perch-Nielsen, 1977); Miocene (NN5), Eq. Atlantic (Perch-Nielsen, 1977); Paleocene (NP5), S. Atlantic (Perch-Nielsen, 1977); Paleocene (NP21, 23 & 25), E. Eq Pacific (Bown & Dunkley Jones, 2012); Paleocene (NP12), E. Indian Ocean (Shamrock & Watkins, 2012); Oligocene (NP14), NW. Atlantic (Bown & Newsam, 2017); Paleocene (NP15), NW. Atlantic (Bown & Newsam, 2017) and Paleocene (NP16), NW. Atlantic (Bown & Newsam, 2017). This species ranges from Paleocene to Miocene ages. The brief distribution of biozones in the study interval has shown in Table 1.

Discussion

Several Cenozoic calcareous nannofossil biozonations have been established over the past four decades (e.g., Martini, 1971, 1976; Bukry, 1973, 1975, 1978; Stow et al. 2013; Toffanin et al., 2013). Backman et al. (2012) made a major revision of the Miocene through Pleistocene calcareous nannofossil biozonations and he stated that these biozonations introduce a consistent result, but other biozonations cannot be reliable (Agnini et al., 2014). Herein, we used Martini's biozonation for the study interval of the Zard-Darreh village in the Alborz Mountains. In this study, 53 species (27 genera and 15 families) of calcareous nannofossils were identified.

This first biozone occurs in the argillaceous limestone and it is characterized by the FO of *Ceratolithoides aculeus* to the FO of *Uniplanarius sissinghii.* Based on the chronostratigraphic chart adapted from Sissingh (1977) emended by Perch-Nielsen (1985) and Burnett (1998), *Ceratolithoides aculeus* suggests the late Early Campanian age (CC20/UC15b^{TP}). This species is associated with other calcareous nannofossils such as *Watznaueria barnesiae*, *Arkhangelskiella cymbiformis*, *Broinsonia parca constricta*, *Micula decussata*, *Eiffelithus eximius*, *Microrhabdulinus ambiguus* and *Prediscosphaera cretacea.* These species are key components of the Late Cretaceous (Perch-Nielsen, 1985; Burnett, 1998; Bown, 1998).

The next biozone NP1 is characterized by presence of calcareous nannofossils including *Biantholithus sparsus*, *Cruciplacolithus primus, Cruciplacolithus intermedius,* and *Cruciplacolithus asymmetricus,* which are critical components of Early Paleocene (Danian) age. The calcareous nannofossils of this biozone are small in size, which may indicate various environmental conditions (e.g., agitation, water-mass temperature, acidity changes (PH), oceanic currents, nutrients). Therefore, based on the preceding biozone (CC20/UC15b^{TP}) and the NP1 biozone, a hiatus is present between the Late Cretaceous and Early Paleocene (Danian) in the Zard-Darreh village, encompasses the latest Late Cretaceous (Maastrichtian) to earliest Early Paleocene (early Danian). This biozone follows with other succeeding biozones of Early Paleocene (NP3-NP8) suggesting Early Paleocene (late Danian-late Thanetian). It should be mentioned, that some calcareous nannofossils are present such as *Sphenolithus* spp. and *Discoaster mohleri* within the Early Paleocene biozones, which might indicate the warming climatic condition toward the Eocene.

Conclusions

In this study, 53 species (27 genera and 15 families) of calcareous nannofossils were identified and 9 biozones were established.

Based on calcareous nannofossils, we recorded the Paleocene strata for the first time in the southern Alborz Mountains.

The study interval was previously assigned to Late Cretaceous by using foraminifers whereas one calcareous nannofossil (CC20/UC15b^{TP}) indicates Late Cretaceous (Campanian) and the remainder (NP2-NP8) suggests the Early Paleocene (Danian-Thanetian).

A hiatus is present between CC20/UC15b^{TP} and NP1 encompasses the latest Late Cretaceous to earliest Early Paleocene (early Danian).

There are some small size calcareous nannofossils such as *Biantholithus sparsus*, *Cruciplacolithus primus, Cruciplacolithus intermedius,* and *Cruciplacolithus asymmetricus,* which may indicate the effect of various environmental factors (e.g., agitation, water-mass temperature, acidity changes (PH), oceanic currents, nutrient).

Some calcareous nannofossils such as *Sphenolithus* spp. and *Discoaster mohleri* are present in NP6 and NP7 Late Paleocene (Selandian-Thanetian) strata of Zard-Darreh village that may indicate the warming climatic condition toward the Eocene.

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References

Allenbach, P., 1966. Geologic und Petrographic des Damavandu nd seincr Umgebtmg (Ze~tral- Elburz) Iran. Mitt. Geology Institue ETH u. University Zurich, 63, 144.

Assereto, R., Ippolito, I., 1964. Osservazioni preliminari sul Cretaceo della bassa valle del Lar (Elburz centrale - Iran). Rivista Italiano Paleontolige e Stratigraphia, 70 (3): 525-534.

Agnini, C., Fornaciari, E., Raffi, R., Catanzariti, R., Pälike, H., Backman, J., Rio, D., 2014. Biozonation and biochronology of Paleogene calcareous nannofossils from low and middle latitudes. Newsletters on Stratigraphy, 47(2): 131-181.

Backman, J., Raffi, I., Rio, D., Fornaciari, E., Palike, H., 2012. Biozonation and biochronology of Miocene through Pleistocene calcareous nannofossils from low and middle latitudes. Newsletters on Stratigraphy, 45: 221-244.

Bown, P., 1998. Calcareous Nannofossil Biostratigraphy. British Micropaleontological Society Publications Series, Chapman and Hall Ltd/Kluwer Academic Press, 315.

Bown, P. R., 2005a. Paleogene calcareous nannofossils from the Kilwa and Lindi areas of coastal Tanzania (Tanzania Drilling Project 2003-4). Journal of Nannoplankton Research, 27 (1): 21-95.

Bown, P. R., 2005b. Selective calcareous nannoplankton survivorship at the Cretaceous-Tertiary boundary. Geology, 33 (8): 653-656.

Bown, P. R., 2010. Calcareous nannofossils from the Paleocene/Eocene Thermal Maximum interval of southern Tanzania (TDP Site 14). Journal of Nannoplankton Research, 31(1): 11-38.

Bown, P. R., Dunkley Jones, T., 2012. Calcareous nannofossils from the Paleogene equatorial Pacific (IODP Expedition 320 Sites U1331-1334). Journal of Nannoplankton Research, 32 (2): 3-51.

Bown, P. R., Gibbs, S. J., Sheward, R., O'Dea, S., Higgins, D., 2014. Searching for cells: the potential of fossil coccospheres in coccolithophore research. Journal of Nannoplankton Research, 34 (special): 5-21.

Bown, P. R., 2016. Paleocene calcareous nannofossils from Tanzania (TDP sites 19, 27 and 38). Journal of Nannoplankton Research, 36 (1): 1-32.

Bown, P. R., Newsam, C., 2017. Calcareous nannofossils from the Eocene North Atlantic Ocean (IODP Expedition 342 Sites U1403-1411). Journal of Nannoplankton Research, 37(1): 25-60

Bukry, D., Percival, S. F., 1971a. New Tertiary calcareous nannofossils. Tulane Studies in Geology and Paleontology, 8: 123-146.

Bukry, D., 1971. Cenozoic calcareous nannofossils from the Pacific Ocean. Transactions of the San Diego Society of Natural History 16: 303-327.

Bukry, D., 1973. Low-latitude coccolith biostratigraphic zonation. In: Edgar, N.T., Saunders, J. B., et al., Initial Reports DSDP 15, Washington (U. S. Govt. Printing Office): 685-703.

Bukry, D., 1975. Coccolith and silicoflagellate stratigraphy, northwestern Pacific Ocean, Deep Sea

Drilling Project Leg 32. In: Larson, R. L., Moberly, R., et al., Initial Reports DSDP 32, Washington (U. S. Govt. Printing Office): 677-701.

Bukry, D., 1978. Biostratigraphy of Cenozoic marine sediments by calcareous nannofossils. Micropaleontology, 24: 44-60.

Burnett, J.A., 1998. Upper cretaceous. In: Bown, P.R., 1998. Calcareous Nannofossil Biostratigraphy. British Micropaleontology Society Publication Series. Chapman and Hall, London, 132-199.

Bralower, T. J., Self-Trail, J., 2016. Nannoplankton malformation during the Paleocene-Eocene Thermal Maximum and its paleoecological and paleoceangraphic significance. Paleoceanography, 31: 1-17.

Bramlette, M. N., Martini, E., 1964. The great change in calcareous nannoplankton fossils between the Maastrichtian and Danian. Micropaleontology, 10 (2): 291-322.

Bramlette, M. N., Sullivan, F. R., 1961. Coccolithophorids and related nannoplankton of the Early Tertiary in California. Micropaleontology, 7(2): 129-188.

Brotzen, F., 1959. On *Tylocidaris* species (Echinoidea) and the stratigraphy of the Danian of Sweden. With a bibliography of the Danian and Paleocene. Sveriges Geologiska Undersokning, Arsbok, 54 (2): 1-81.

Bybell, L., 1975. Middle Eocene calcareous nannofossils at Little Stave Creek, Alabama. Tulane Studies in Geology and Paleontology, 11(4): 177-247.

Bybell, L. M., Self-Trail, J., 1995. Evolutionary, biostratigraphic and taxonomic study of calcareous nannofossils from a continuous Palaeocene-Eocene boundary section in New Jersey. U.S. Geological Survey, Professional Paper, 1554: 1-36.

Bybell, L., Self-Trail, J., 1997. Late Paleocene and Early Eocene calcareous nannofossils from three boreholes in an onshore-offshore transect from New Jersey to the Atlantic continental rise. Proceedings of the Ocean Drilling Program, Scientific Results, 150: 91-110.

Dellenbach, J., 1964. Contribution a l'etude geologique de la region situee ä l'est de Teheran (Iran). Thesis, University of Strasbourg (unpublished).

Deflandre, G., Fert, C., 1954. Observations sur les coccolithophoridés actuels et fossiles en microscopie ordinaire et électronique. Annales de Paléontologie, 40: 115-176.

Dunkley Jones, T., Bown, P. R., Pearson, P., 2009. Exceptionally well-preserved upper Eocene to lower Oligocene calcareous nannofossils (Prymnesiophycidae) from the Pande Formation (Kilwa Group), Tanzania. Journal of Systematic Palaeontology, 7 (4): 359-411.

Gardin, S., 2002. Late Maastrichtian to early Danian calcareous nannofossils at Elles (Northwest Tunisia). A tale of one million years across the K-T boundary. Palaeogeography, Palaeoclimatology, Palaeoecology, 178: 211-231.

Gardin, S., Monechi, S., 1998. Palaeoecological change in middle to low latitude calcareous nannoplankton at the Cretaceous/Tertiary boundary. Bulletin de la Société Geologique de France. 169: 5. 709-723.

Gartner, S., 1971. Calcareous nannofossils from the JOIDES Blake Plateau cores and revision of the Paleogene nannofossil zonation. Tulane Studies in Geology and Paleontology, 8: 101-121.

Ghiasi, M., 1993. Microstratigraphy of Upper Cretaceous sediments in the East and North East of Tehran, unpublished MSC Thesis, Collage of Earth Sciences, University of Shahid Beheshti, 315.

Gohrbandt, K., 1963. Zur Gliederung des Palaogen im Helvetikum nordlich Salzburg nach planktonischen Foraminiferen. Mitteilungen der Geologischen Gesellschaft in Wien, 56: 1-116.

Haq, B. U., Aubry, M. P., 1980. Early Cenozoic calcareous nannoplankton biostratigraphy and palaeobiogeography of North Africa and the Middle East and trans-Tethyan correlations. *In*, Salem, M. J. and Busrewil, M. T. (eds) The Geology of Libya. Academic Press, London, 271-304.

Hattner, J. G. & Wise, S. W. (1980). Upper Cretaceous calcareous nannofossil biostratigraphy of South Carolina. South Carolina Geology, 24: 41-17.

Hay, W.W., Mohler, H. P., Roth, P. H., Schmidt, R. R., Boudreaux, J. E., 1967. Calcareous nannoplankton zonation of the Cenozoic of the Gulf Coast and Caribbean-Antillean area, and transoceanic correlation. Transactions of the Gulf-Coast Association of Geological Societies, 17: 428-480.

Hay, W.W., Mohler, H. P., 1967. Calcareous nannoplankton from Early Tertiary rocks at Point Labau, France and Paleocene-Early Eocene correlations. Journal of Paleontology, 41(6): 1505-1541.

Jones, A. P., Dunkley Jones, T., 2020. Middle Eocene to Early Oligocene calcareous nannofossils from the Nanggulan Formation, Java, Indonesia. Journal of Nannoplankton Research, 30 (1): 57-79.

Lees, J. A. Bown, P. R., 2005. Upper Cretaceous calcareous nannofossil biostratigraphy, ODP Leg 198 (Shatsky Rise, Northwest Pacific Ocean). Proceedings of the Ocean Drilling Program, Scientific Results. 198: 1-60.

Mai, H., 2001. New coccolithophorid taxa from the Guelhemmerberg airshaft. Lower Paleocene, The Netherlands. Micropaleontology, 47: 144-154.

Mai, H., Romein, A.J.T., Willems, H., 1994. Coccospheres of a rare nannofossil species: Biantholithus sparsus Bramlette and Martini, 1964. Marine Micropaleontology, 24: 1-2.

Mai, H., von Salis, K., Willems, H., Romein, A. J. T., 1997. Fossil coccospheres from the K/T boundary section from Geulhemmerberg, The Netherlands. Micropaleontology, 43: 281-302

Mai, H., Hillebrandt-Habel, T., von Salis Perch-Nielsen, K., Willems, H., 1998. Paleocene coccospheres from DSDP Leg 39, Site 356, Sao Paulo Plateau, S. Atlantic Ocean. Journal of Nannoplankton Research, 20(1): 21-29.

Martini, E., 1971. Standard Tertiary and Quaternary calcareous nannoplankton. In: A Farinacci (Ed.), Proceedings Planktonie Conference, Romania, 2: 739-85.

Martini, E., 1976. Cretaceous to Recent Calcareous Nannoplankton from the Central Pacific Ocean (DSDP Leg 33). In: Schlanger, S. O., Jackson, E. D. et al., Initial Reports DSDP 33: Washington (U. S. Govt. Printing office): 383-423.

Monechi, S., Reale, V., Bernaola, G., Balestra, B., 2013. The Danian/Selandian boundary at Site 1262 (South Atlantic) and in the Tethyan region: Biomagnetostratigraphy, evolutionary trends in Fasciculiths and environmental effects of the Latest Danian Event. Marine Micropaleontology, 98 (1): 28-40.

Müller, C., 1974. Calcareous nannoplankton, Leg 25 (Western Indian Ocean). Initial Reports of the Deep-Sea Drilling Project, 25: 579-633.

Müller, C., 1979. Calcareous nannofossils from the North Atlantic (Leg 48). Initial Reports of the Deep-Sea Drilling Project, 48: 589-639.

Okada, H., Thierstein, H. R., 1979. Calcareous nannoplankton - Leg 43, Deep Sea Drilling Project. Initial Reports of the Deep-Sea Drilling Project, 43: 507-573.

Perch-Nielsen, K., 1969a. Die Coccolithen einiger danischer Maastrichtien- und Danien lokalitaten. Meddelelser fra Dansk Geologisk Forening, 19: 51-68.

Perch-Nielsen, K., 1969b. Elektronenmikroskopische Untersuchungen der Coccolithophoriden der Dan-Scholle von Katharinenjof (Fehmarn). Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, 132: 317-332.

Perch-Nielsen, K., 1971a. Elektronenmikroskopische untersuchungen an Coccolithen und verwandten Formen aus dem Eozan von Danemark. Biologiske Skrifter, Kongelige Danske Videnskabernes Selskab, 18(3): 1-76.

Perch-Nielsen, K., 1971b. Einige neue Coccolithen aus dem Paläozän der Bucht von Biskaya und dem Eozän der Labrador See. Bulletin of the Geological Society of Denmark, 21: 347-361.

Perch-Nielsen, K., 1972. Remarks on Late Cretaceous to Pleistocene coccoliths from the North Atlantic. Initial Reports of the Deep-Sea Drilling Project, 12: 1003-1069.

Perch-Nielsen, K., 1977. Albian to Pleistocene calcareous nannofossils from the Western South Atlantic, DSDP Leg 39. Initial Reports of the Deep-Sea Drilling Project, 39: 699-823.

Perch-Nielsen, K., 1979. Calcareous nannofossil zonation at the Cretaceous/Tertiary boundary in Denmark. In, Birkelund, T. and Bromley, R.G. (eds), Proceedings Cretaceous-Tertiary Boundary Events Symposium, Copenhagen, 1. Copenhagen, 115-135.

Perch-Nielsen, K., 1981b. New Maastrichtian and Paleocene calcareous nannofossils from Africa, Denmark, and USA and the Atlantic, and some Paleocene lineages. Eclogae Geologicae Helvetiae, 74 (3): 831-863.

Perch-Nielsen, K., 1985. Cenozoic calcareous nannofossils. In, Bolli, H. M., Saunders, J. B. and Perch-Nielsen, K. (eds), Plankton Stratigraphy. Cambridge University Press, Cambridge, 427-555.

Pospichal, J.J., Wise, S.W., 1990a. Calcareous nannofossils across the K/T boundary, ODP hole 690C, Maud Rise, Weddell Sea. Proceedings of the Ocean Drilling Program, Scientific Results, 113: 515-532.

Pospichal, J.J., Wise, S.W., 1990b. Paleocene to Middle Eocene calcareous nannofossils of ODP sites 689 and 690, Maud Rise, Weddell Sea. Proceedings of the Ocean Drilling Program, Scientific Results, 113: 613-638.

Romein, A.J.T., 1979. Lineages in Early Paleogene calcareous nannoplankton. Utrecht Micropaleontological Bulletin, 22: 1-231.

Romein, A.J.T., Willems, H., Mai, H., 1996. Calcareous nannoplankton of the Geulhemmerberg K/T boundary section, Maastrichtian type area, the Netherlands. Geologie en Mijnbouw, 75: 231-238.

Sadeghi, A., 1999. Investigation of Upper Cretaceous sediments in the Alborz Basin. unpublished Ph.D. Thesis, College of Earth Sciences, University of Shahid Beheshti, 656.

Self-Trail, J., 2011. Paleogene Calcareous Nannofossils of the South Dover Bridge core, Southern Maryland (USA). Journal of Nannoplankton Research, 32(1): 1-28.

Self-Trail, J.M., Powars, D.S., Watkins, D.K., Wandless, G.A., 2012. Calcareous nannofossil assemblage changes across the Paleocene-Eocene Thermal Maximum: Evidence from a shelf setting. Marine Micropaleontology, 92-93: 61-80.

Shamrock, J. L., Watkins, D. K., 2012. Eocene calcareous nannofossil biostratigraphy and community structure from Exmouth Plateau, Eastern Indian Ocean (ODP Site 762). Stratigraphy, 9 (1): 1-11.

Shepherd, C. L., Kulhanek, D. K., 2016. Eocene nannofossil biostratigraphy of the mid-Waipara River section, Canterbury Basin, New Zealand. Journal of Nannoplankton Research, 26 (1): 33-59.

Sissingh, W. (1977). Biostratigraphy of Cretaceous calcareous nannoplankton. Geologie en Mijnbouw, 65(1): 37-65.

Steiger, R. 1966. Die Geologie der West-Firuzkuh-Area (Zentral Elburz/Iran). Geologisches Institute der Eidgenosischen Technischen Hochschule und der Universitat Zürich, 68: 1-145.

Steurbaut, E., Sztrákos, K., 2008. Danian/Selandian boundary criteria and North Sea Basin-Tethys correlations based on calcareous nannofossil and foraminiferal trends in SW France. Marine Micropaleontology, 67: 1-29.

Stöcklin, J., Setudehnia, A., 1991. Stratigraphy Lexicon of Iran. Geological Survey of Iran, 18:376.

Stow, D. A.V., Hernandez-Molina, F. J., Alvarez Zarikian, C. A., and the Expedition 339 Scientists, 2013. Proceedings IODP, 339: Tokyo (Integrated Ocean Drilling Program Management International, Inc.). doi:10.2204/iodp.proc.339.2013

Stradner, H., 1961. Vorkommen von Nannofossilien im Mesozoikum und Alttertiär. Erdoel-Zeitschrift, 77(3): 77-88.

Stradner, H., 1963. New contributions to Mesozoic stratigraphy by means of nannofossils. Proceedings of the Sixth World Petroleum Congress, Section 1, Paper 4: 167-183.

Stradner, H., Aubry, M. P., Bonnemaison, M., 2010. Calcareous nannofossil type specimens in the collection of the Geological Survey of Austria: A taxonomic and stratigraphic update. Jahrbuch der Geologischen Bundesanstalt, 150 (1-2): 9-84.

Steurbaut, E., 1998. High-resolution holostratigraphy of Middle Paleocene to Early Eocene strata in Belgium and adjacent areas. Palaeontographica Abteilung A Palaeozoologie Stratigraphie, 247: 91-256.

Steurbaut, E., 2011. New calcareous nannofossil taxa from the Ypresian (Early Eocene) of the North Sea Basin and the Turan Platform in West Kazakhstan. Bulletin de l'Institut Royal des Sciences Naturelles de Belgique Sciences de la Terre, 81: 247-277.

Sullivan, F.R., 1964. Lower Tertiary nannoplankton from the California Coast Ranges. I. Paleocene. University of California Publications in Geological Sciences, 44: 163-227.

Theodoridis, S., 1984. Calcareous nannofossil biostratigraphy of the Miocene and revision of the *helicoliths* and *discoasters*. Utrecht Micropaleontological Bulletin, 32: 1-271.

Thibault, N., 2010. Calcareous nannofossils from the boreal Upper Campanian- Maastrichtian chalk of Denmark. Journal of Nannoplankton Research, 31 (1): 39-56.

Thibault, N., Minoletti, F., Gardin, S., 2018. Offsets in the early Danian recovery phase in carbon isotopes: Evidence from the biometrics and phylogeny of the *Cruciplacolithus* lineage. Revue de Micropaléontologie, 61(2): 207-221.

Toffanin, F., Agnini, C., Rio, D., Acton, G., Westerhold, T., 2013. Middle Eocene to early Oligocene calcareous nannofossil biostratigraphy at IODP Site U1333 (equatorial Pacific). Micropaleontology, 59: 1-14.

Roth, P.H., 1973. Calcareous nannofossils-LEG 17, DSDP, 17: 695-795.

van Heck, S. E., Prins, B., 1987. A refined nannoplankton zonation for the Danian of the Central North Sea. Abhandlungen der Geologischen Bundesanstalt, 39: 285-303.

Varol, O., 1989. Palaeocene calcareous nannofossil biostratigraphy. In, Crux, J. A. and van Heck, S. E.

(eds) Nannofossils and their applications: Proceedings of the 2nd INA Conference, London 1987. British Micropalaeontological Society Publication Series, 265-310.

Varol, O., Jakubowski, M., 1989. Some new nannofossil taxa. INA Newsletter, 11: 24-29.

Varol, O., 1992. *Sullivania* a new genus of Palaeogene coccoliths. Journal of Micropalaeontology, 11: 141-150.

Varol, O., 1998. Palaeogene. In, Bown, P. R. (ed.) Calcareous Nannofossil Biostratigraphy. British Micropalaeontological Society Publication Series, 200-224.

Watkins, D.K., Wise, S.W. Jr., Pospichal, J.J., Crux, J., 1996. Upper Cretaceous calcareous nannofossil biostratigraphy of the Southern Ocean. In: Whateley, R., Mogulevsky, A., (Eds.), Microfossil and oceanic environments, University of Whale Aberystwyth Press, Aberystwyth.

Watkins, D. K., 2007. Cretaceous Calcareous Nannofossil from DSDP Leg 77, Southeast Gulf of Mexico, No. 77.

Wei, W., 1988. *Heliolithus bukryi* a new Upper Paleocene calcareous nannofossil. INA Newsletter, 10: 90-93.

Wise, S. W., Wind, F. H., 1977. Mesozoic and Cenozoic calcareous nannofossils recovered by DSDP Leg 36 drilling on the Falkland Plateau, south-west Atlantic sector of the Southern Ocean. Initial Reports of the Deep-Sea Drilling Project, 36: 269-491

Wise, S. W., 1983. Mesozoic and Cenozoic calcareous nannofossils recovered by DSDP Leg 71 in the Falkland Plateau region, Southwest Atlantic Ocean. Initial Reports of the Deep-Sea Drilling Project, 71: 481-550.

Young, J. R., 1998. Neogene. In, Bown, P. R. (ed.) Calcareous Nannofossil Biostratigraphy. British Micropalaeontological Society Publication Series, 225-265.

Taxonomic Index:

Alphabetical list of calcareous nannofossil species cited in the text, figures, plates, and Table.
Arkhangelskiella cymbiformis Vekshina, 1959
Biantholithus sparsus Bramlette & Martini, 1964
Broinsonia parca sub sp. *constricta* Hattner et al., 1980
Chiasmolithus bidens (Bramlette & Sullivan, 1961) Hay & Mohler, 1967
Braarudosphaera bigelowii (Gran & Braarud 1935) Deflandre, 1947
Chiasmolithus danicus (Brotzen, 1959) Hay & Mohler, 1967
Neochiastozygus rosenkrantzii (Perch-Nielsen, 1971) Varol, 1989
Coccolithus plagicus (Wallich, 1871) Schiller, 1930
Cruciplacolithus neohelis (McIntyre & Bé 1967) Reinhardt, 1972
Cruciplacolithus primus Perch-Nielsen, 1977
Cruciplacolithus asymmetricus van Heck & Prins, 1987
Cruciplacolithus edwardsii Romein, 1979
Cruciplacolithus frequens (Perch-Nielsen, 1977) Romein, 1979
Cruciplacolithus intermedius van Heck & Prins, 1987
Cruciplacolithus latipons Romein, 1979
Cruciplacolithus tenuis (Stradner, 1961) Hay and Mohler *in* Hay *et al.*, 1967
Discoaster mohleri Bukry & Percival, 1971
Eiffellithus eximius (Stover, 1966) Perch-Nielsen, 1968
Ellipsolithus macellus (Bramlette & Sullivan, 1961) Sullivan, 1964
Fasciculithus involutus Bramlette & Sullivan, 1961
Fasciculithus tympaniformis Hay & Mohler *in* Hay *et al.*, 1967
Heliolithus kleinpellii Sullivan, 1964
Heliolithus riedelii Bramlette & Sullivan 1961
Markalius inversus (Deflandre *in* Deflandre and Fert, 1954) Bramlette and Martini, 1964
Micula decussata Vekshina, 1959
Microrhabdulinus ambiguus (curve spine) Deflandre, 1963
Neochiastozygus modestus Perch-Nielsen, 1971
Prediscosphaera cretacea (Arkhangelsky, 1912) Gartner, 1968
Prinsius martinii (Perch-Nielsen, 1969) Haq, 1971
Placozygus spiralis (Bramlette & Martini, 1964) Hoffmann, 1970
Sphenolithus moriformis (Brönnimann & Stradner, 1960) Bramlette & Wilcoxon, 1967
Toweius Hay and Mohler, 1967
Watznaueria barnesiae (Black *in* Black & Barnes, 1959) Perch-Nielsen, 1968
Zygrhablithus bijugatus (Deflandre in Deflandre and Fert, 1954) Deflandre, 1959
Zygodiscus herlyni Sullivan 1964
Zeugrhabdotus sigmoides (Bramlette & Sullivan, 1961) Bown & Young, 1997
Zygodiscus sheldoniae Bown, 2005