Calcareous nannofossils biostratigraphy of the Campanian-Danian interval, Gurpi Formation in the Zagros Basin, SouthWest of Iran

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Abstract

This study presents calcareous nannofossils biostratigraphy of the Campanian–Danian interval at the Gurpi Formation in the southwest of Ilam Province at the Zagros Basin. The studied sequence of the Gurpi Formation mainly consists of marly shale and limestones. The thickness of Gurpi Formation was measured as approximately 230 m. Forty-five species belonging to twenty-eight genera were recorded in these strata. The biostratigraphy based on calcareous nannofossil assemblages allows the identification of nannofossil standard zones such as CC18b, CC19, CC20, CC21, CC22, CC25b,c and CC26b, that equivalent to UC14c^{TP} - UC20d^{TP} for Cretaceous, and NP2 - NP3 (equivalent CNP2, CNP3 and lower part of CNP4) for the Paleogene strata in the Gurpi Formation. The studied section spans the early Campanian to early late Campanian with good continuity. A biostratigraphic gap was identified in the late late Campanian to early Maastrichtian (CC23, CC24, and CC25a), across the late Maastrichtian (CC26a) and early Danian (NP1).

Keywords: *Biostratigraphy, Calcareous Nannofossils, Cretaceous, Paleogene, Zagros Basin.*

Introduction

During the Mesozoic and Cenozoic eras, a thick sedimentary sequence of more than 10000 m composed mainly of marine sediments was deposited at the Zagros Basin (Motiei, 1995). The Gurpi Formation (=Fm.) is part of the Cretaceous - Paleogene deposits, with good lateral continuity in the Khuzestan, Lurestan, and Fars Provinces in the Zagros Basin. The type section of the Gurpi Fm. is located at the north of the Lali oilfield and northeast of Masjed-Soleiman, and it is mainly composed of argillaceous limestones with grey marls and marly shales (James & Wynd, 1965; Stocklin & Setudehnia, 1971). In the type section of Gurpi Fm., this formation unconformably overlies the Ilam Fm., and it is covered conformably by the Pabdeh Fm. The Gurpi Fm. is highly fossiliferous and has been investigated from different aspects of palaeontology, such as foraminiferal data, dinoflagellates, palynomorphs, macrofossils, microfacies, as well as sedimentary environments (e.g., Vaziri Moghaddam, 2002; Mohseni & Al-Aasm, 2004; Ghasemi-Nejad *et al*., 2006; Darvishzadeh *et al*., 2007; Bahrami, 2009; Behbahani *et al*., 2010; Asgharian Rostami, 2013; Beiranvand *et al.,* 2013, 2014; Fereydonpour *et al*., 2014). All these studies revealed that the age of the Gurpi Fm. varies in different locations at Zagros Basin. In recent years, several sections of the Gurpi Fm. in the Zagros Basin were studied based on calcareous nannofossils (e.g., Hadavi & Ezadi, 2007; Senemari & Sohrabi Molla Usefi, 2013; Mahanipour *et al.,* 2013; Razmjooei *et al.,* 2014; Najafpour & Mahanipour, 2015; Mahanipour & Najafpour, 2016; Razmjooei *et al.,* 2018). Many studies have been done on the Cretaceous - Paleogene boundary at this formation in the Zagros Basin (Parandavar *et al.,* 2013; Foroughi & Aryanasab, 2018) and also from different parts of the world (e.g., Stinnesbeck & Keller, 1995; Molina *et al.,* 2006; Coccioni & Marsili, 2007; Alegret & Thomas, 2013). However, this research mainly concentrated on the age determination of the Gurpi Fm. based on calcareous nannofossils from Ilam Province. In fact, the main purpose of this research was to document the calcareous nannofossils assemblages and determine the exact age of the strata.

Geological setting

The Zagros Basin is a part of the Alpine-Himalayan belt (Motiei, 1993). The collision between the Arabian plate and the Iranian continental block produced the Zagros folded belt extending for about 2000 Km from southeastern Turkey to southwest Iran (Motiei, 1995; Kamali *et al*., 2006). The Cretaceous deposits have widespread outcrops in the Zagros folded belt. In this basin, the Gurpi Fm. is composed of grey to olive greenish marly shale and limestone beds. The studied section is located in the Cham-Ab village, about 25 Km southwest of Ilam, at the Lurestan Province. The coordinates for the base of the section are 33°35' N and 46°15' E (Fig. 1). The thickness of Gurpi Fm. was measured as approximately 230 m. At the studied interval the Gurpi Fm. overlays the Ilam Fm. non-continuously, and continuously covered by the Pabdeh Fm. (Fig. 2).

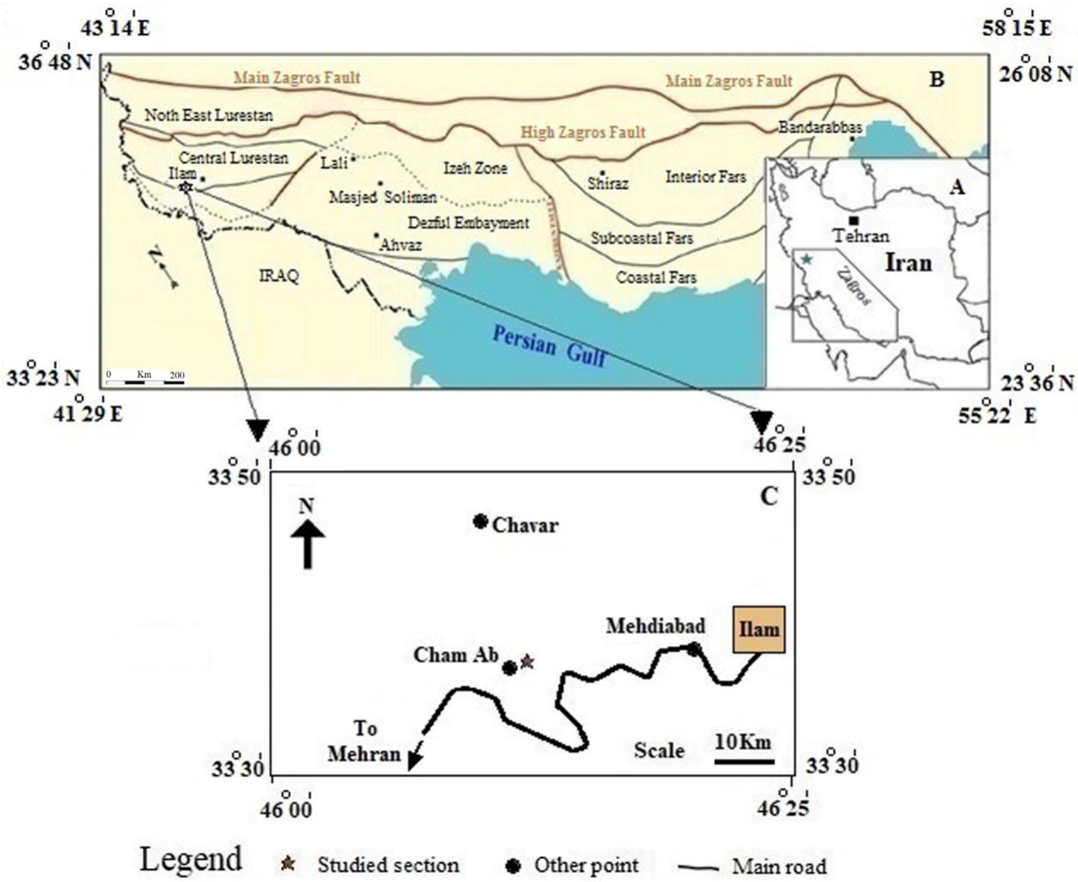


Figure 1. A- General map of Iran, along with the location of Zagros Basin and the studied section. B- Location map of the studied area in the central Lurestan zone, in the Zagros Basin, after Motiei (1993). C- The location map of the studied section in southwest Ilam is marked by a star.

Figure 2. The boundary between Gurpi and Pabdeh formations in the studied section.

Materials and methods

A total of 105 samples were obtained from the intervals of the Gurpi Fm. at Cham-Ab section. Samples were prepared following the standard smear slide technique (Bown & Young, 1998). Smear slides were made directly from unprocessed samples, freshly cut rock fragments without centrifuging in order to avoid changes in the composition of the original assemblages. All slides were studied under crossed polarized light (XPL) and the plane polarized light (PPL) of BH2 Olympus microscope at X1000 magnification. For each slide, five to seven traverses (approximately 1000 fields of View, FOVs) were counted to identify the First Occurrence (FO) and Last Occurrence (LO) of each taxon. The preservation of nannofossils was evaluated qualitatively by using visual criteria concerning degree of etching and overgrowth (Roth, 1973; Watkins, 2007) which ranges from Good (G) to Poor (P) at the studied section. In this study, for the identification of taxa, bibliographic references Perch-Nielsen (1985 a, b) and Burnett (1998) have been used. For biostratigraphic analysis references of Martini (1971), Sissingh (1977), Perch-Nielsen (1985 a, b), Burnett (1988) and Agnini *et al.* (2014) have been applied. The taxa in this study are illustrated in Figure 4 and Plates (1 & 2).

Results

As a result of this study, 28 genera and 45 species of calcareous nannofossils (36 Cretaceous species and 9 Paleocene species) have been identified at the Gurpi Fm. in Cham-Ab section, located in Zagros Basin, at southwestern of Iran. The studied samples belong to a sedimentary sequence of about 230 m of marly shales and limestones (Fig. 3). The stage boundaries were determined via comparisons with standard calcareous nannofossil zonal schemes from the standard zonal schemes (e.g., Martini, 1971; Sissingh, 1977; Burnett, 1998; Agnini *et al.,* 2014). Our results allow reviewing the accurate position of the early Campanian (CC21/UC15c^{TP}) to late Campanian (CC23b/UC16), late late Maastrichtian (CC26b/UC20d^{TP}) and early Danian to late Danian (NP2/NP3 or CNP3) stage boundaries based on calcareous nannofossil bio-events. Also, sensible hiatus is recorded across the K/Pg boundary with the complete absence of the NP1.

Nannofossil Preservation, Diversity, and Abundance

The preservation of the nannofossil assemblages is good (G) to poor (P) at the studied section, and many biostratigraphic marker species have been recognized. The abundance and diversity of calcareous nannofossils at the base of successions are decreased upwards.

Biostratigraphy and bio-events

Calcareous nannofossils recorded in the Mesozoic and Cenozoic strata have been used as an appropriate tool for biostratigraphic analysis (Perch-Nielsen, 1985; Thierstein & Young, 2004). The continued evolution of many forms of calcareous nannofossils during the 14 million years (81.5- 67.5 Ma) from the early Campanian to the late Maastrichtian has enabled the recognition of seven biostratigraphic zonal units on the basis of the relative ranges of various species (Perch-Nielsen, 1985; Gradstein *et al*., 2012). Also, the evolution of calcareous nannofossils during the 2.1 million years (64.9- 62.8 Ma) early to late Danian has enabled us to identify two biostratigraphic zones at the upper part of the Gurpi Fm. in the studied section. Accordingly, this study presents a biostratigraphic framework based on the first occurrences (FO) and last occurrences (LO), with probable regional significances of the following taxa: the FO of *Aspidolithus parcus parcus* (*=Broinsonia parca parca*), *Ceratolithoides verbeekii, Ceratolithoides aculeus, Quadrum sissinghii* (*=Uniplanarius sissinghii*)*, Quadrum trifidum* (*=Uniplanarius trifidus*)*, Lithraphidites quadratus, Micula murus, Micula prinsii, Thoracosphaera operculata, Cruciplacolithus tenuis, Chiasmolithus danicus, Coccolithus pelagicus* and *Prinsius martini,* and the LO of *Marthasterites furcatus, Lithastrinus grillii, Reinhardtites anthophorus, Eiffellithus eximius* and *Reinhardtites levis* (Table 1) (Plates 1-2).

Based on the indexed taxa, the following bio-zones were recognized: Aspidolithus parcus Zone (early Campanian- subzone CC18b/ UC14c^{TP}-UC14d^{TP}), Calculites ovalis Zone (late early Campanian- CC19/UC14d^{TP}- UC15a^{TP}), Ceratolithoides aculeus Zone (late early Campanian-CC20/UC15b^{TP}), Quadrum sissinghii Zone (early late Campanian- CC21/UC15c^{TP}), Quadrum trifidum Zone (late late Campanian-CC22/UC15d,e^{TP}), Arkhangelskiella cymbiformis Zone (early late Maastrichtian- subzone CC25b, c/UC20a,b^{TP}), and Nephrolithus frequens Zone (late late Maastrichtian- subzone CC26b/UC20d^{TP}) for the investigated part of the succession (200 meters from the base of the sequence), and the end of the succession is characterized by Cruciplacolithus tenuis Zone (early Danian-NP2/CNP2-CNP3) and Chiasmolithus danicus Zone (late Danian-NP3/CNP3-CNP4) in the Paleogene period. The last two zones are equivalent to CNP2 and the lower part of CNP4 of Agnini *et al*.'s (2014) zonation. Additionally, between CC22 and CC25b bio-zones, and CC26b and NP2 bio-zones, an interval lacking calcareous nannofossils was identified in the Cham-Ab section. The bio-zones recognized herein are shown in Fig. 3 and were compared with the worldwide standard zonation of calcareous nannofossils. Bio-zones introduced at the studied section are described below:

a. Aspidolithus parcus Zone (CC18b/UC14c^{TP} - UC14d^{TP}), early Campanian

This bio-zone is recorded from the FO of *Aspidolithus parcus parcus* (0.3 m, Sample No. 1) to the last occurrences (LO) of *Marthasterites furcatus* (23.3 m, Sample No. 8) and corresponds to the early Campanian (Perch-Nielsen, 1985a). Sissingh and Burnett's zoning markers such as *Aspidolithus parcus parcus* (*Broinsonia parca parca*), *Aspidolithus parcus constrictus* (=*Broinsonia parca constricta*) and *Bukryaster hayi* are observed simultaneously at the lower part of this zone (0.3 m from the base of the Gurpi Fm), indicates CC18b. Subzone CC18b is equivalent to UC14c^{TP} and the lower part of UC14d^{TP} of the Burnett zonation (1998). The FO of *Ceratolithoides verbeekii* (8.1 m) recorded at the top of CC18b of Sissingh (1977) zonation and lower part of UC14d^{TP} subzone of Burnett zonation (1998). The thickness of this zone was measured to be 23 m (Sample Nos. 1 to 8).

b. Calculites ovalis Zone (CC19/UC14d^{TP} - UC15a^{TP}), late early Campanian

This bio-zone is defined as the interval from the LO of *Marthasterites furcatus* (23.3 m, Sample No. 8) to the FO of *Ceratolithoides aculeus* (45.2 m, Sample No. 17) and corresponds to the late early Campanian (Perch-Nielsen, 1985a).

According to the Burnett zonation (1998), the first occurrence of *Misceomarginatus pleniporus* is applied for the base of UC15 zone that was not recorded at the studied interval. Therefore, the lower boundary of this zone (UC15a^{TP}) has not been determined.

Table 1. Calcareous nannofossil bio-events of the Gurpi Formation at the studied interval, in the Zagros Basin.

Nannofossil bioevents in cham-Ab section	**Thickness (m)**	**Sample No.**
FO of *Prinsius martini* (NP3)	228 m	100
FO of *Chiasmolithus danicus*	224.7 m	95
FO of *Coccolithus pelagicus*	218 m	87
FO of *Cruciplacolithus tenuis* (NP2)	217.8 m	86
FO of *Micula prinsii* (CC26)	200.1 m	78
FO of *Micula murus* (CC25)	177 m	63
FO of *Lithraphidites quadratus* (CC25)	160.1 m	59
LO of *Reinhardtites anthophorus* (CC22)	121.1 m	44
LO of *Eiffellithus eximius*	121.1 m	44
LO of *Lithastrinus grillii*	104 m	39
FO of *Reinhardtites levis*	99 m	37
FO of *Uniplanarius trifidus* (CC22)	94.2 m	35
FO of *Uniplanarius sissinghii* (CC21)	72.2 m	27
FO of *Ceratolithoides aculeus* (CC20)	45.2 m	17
LO of *Bukryaster hayi*	27.2 m	10
LO of *Marthasterites furcatus* (CC19)	23.3 m	8
FO of *Ceratolithoides verbeekii*	16 m	5
FO of *Broinsonia parca constricta*	Base of section	1
FO of *Broinsonia parca parca* (CC18)	Base of section	1
FO of *Bukryaster hayi* (CC18)	Base of section	1

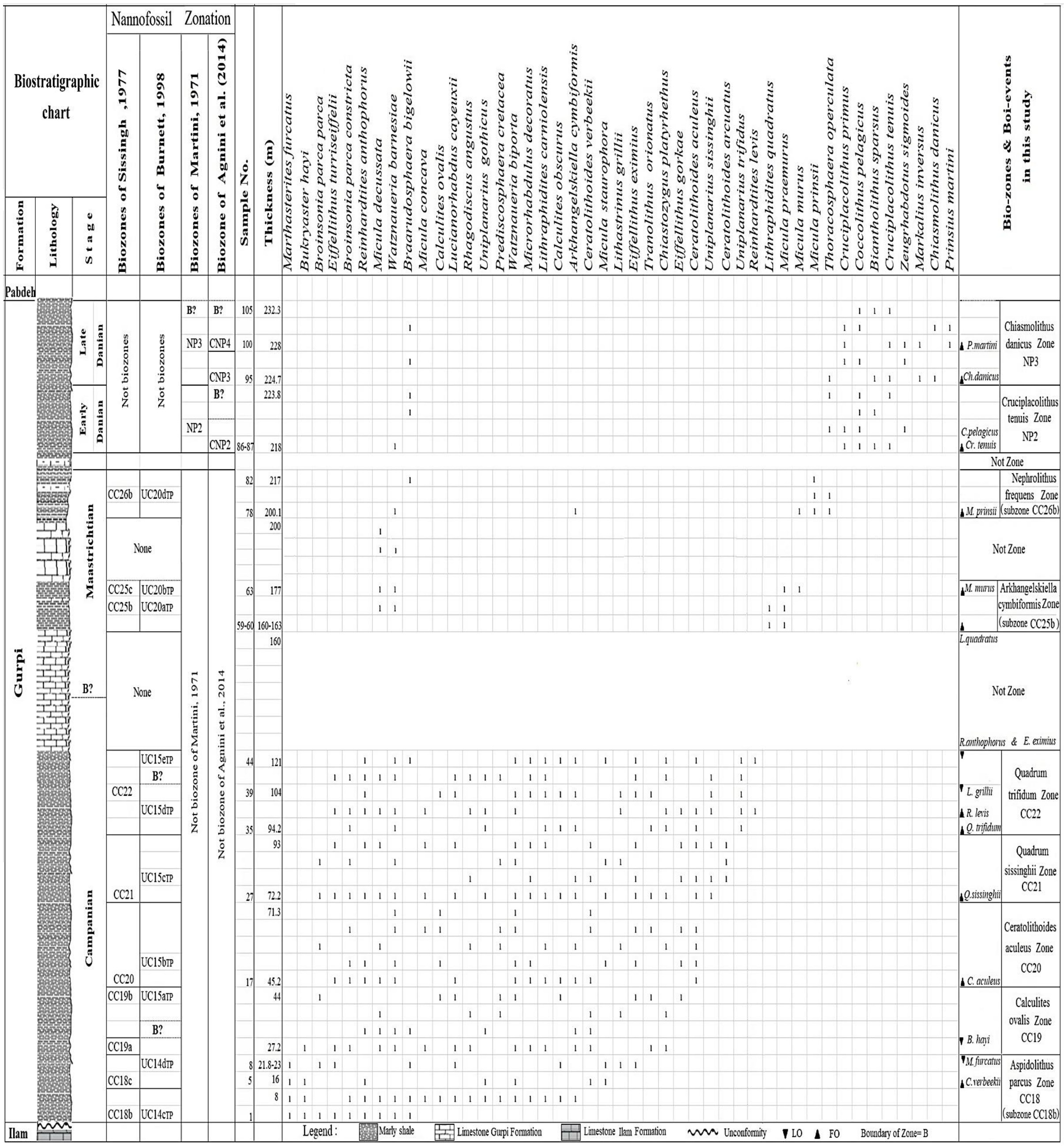


Figure 3. Biostratigraphic chart of Gurpi Fm. based on Calcareous nannofossils, in the studied section.

This zone is equivalent to the upper part of UC14d^{TP} and UC15a^{TP} of the Burnett zonation (1998). The thickness of this zone has been measured as approximately 22 m (Sample Nos. 8 to 17).

c. Ceratolithoides aculeus Zone (CC20/UC15b^{TP}), late early Campanian

The Ceratolithoides aculeus Zone has been expanded from the interval of the FO of *Ceratolithoides aculeus* (45.2 m, Sample No. 17) to the FO of *Quadrum sissinghi* (=*Uniplanarius sissinghii*) (72.2 m, Sample No. 27). This zone is equivalent to UC15b^{TP} of the Burnett zonation (1998). The age of this biozone is late early Campanian with a thickness of approximately 27 m (Sample Nos. 17 to 27).

d. Quadrum sissinghii Zone (CC21/UC15c^{TP}), early late Campanian

This zone is described from the FO of *Uniplanarius sissinghii* (72.2 m, Sample No. 27) to the FO of *Quadrum trifidus* (=*Uniplanarius trifidus*) (94.2 m, Sample No. 35), that corresponds to the early late Campanian. This bio-zone is equivalent to UC15c[TP] subzone of Burnett zonation (1998). The thickness of the zone has been measured approximately 22 m (Sample Nos. 27 to 35).

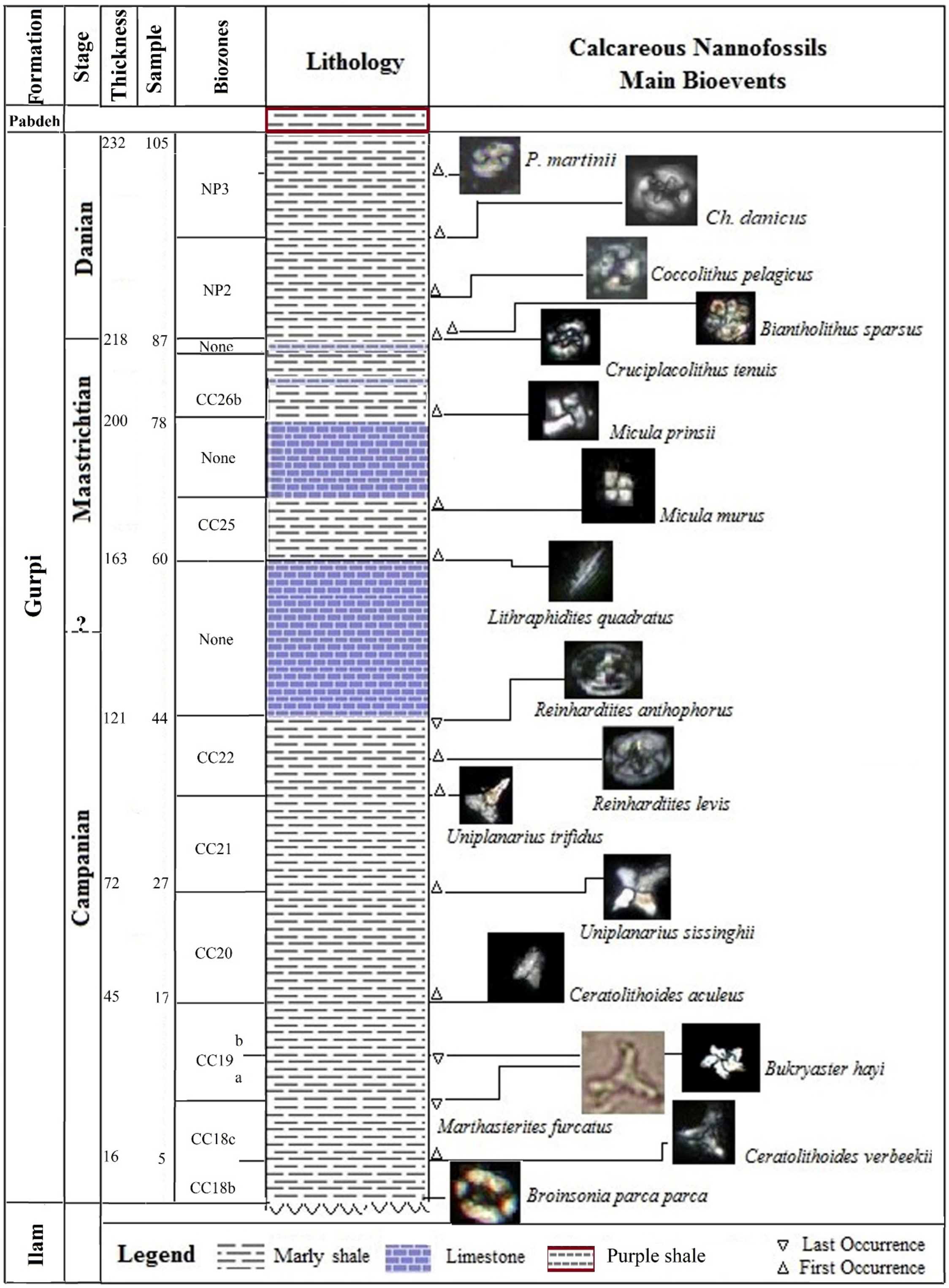


Figure 4. A summary of biostratigraphic and lithostratigraphic distribution at the Gurpi Fm. in the studied section.

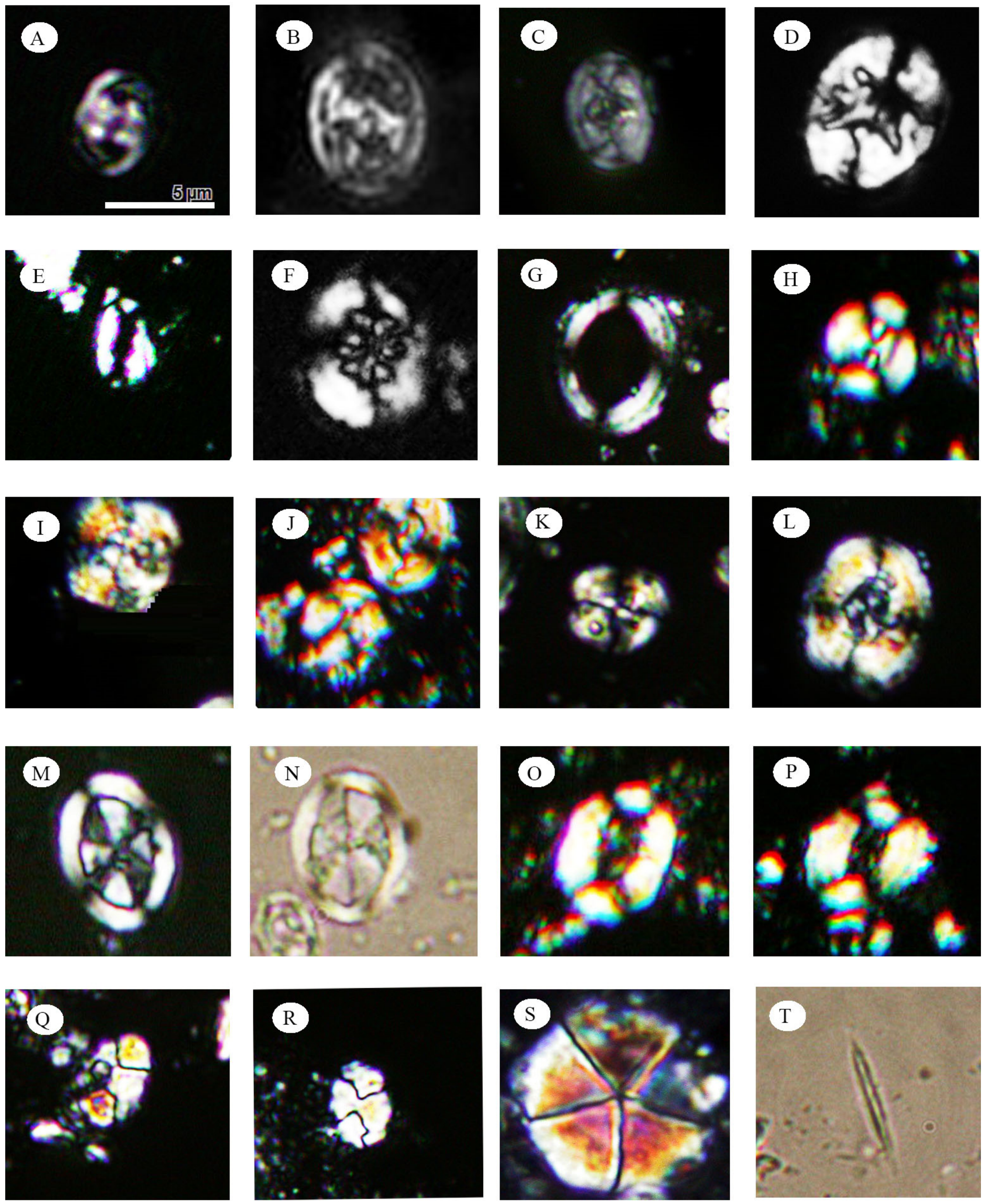


Plate 1. Cross polarised light (XPL) and plane polarised light (PPL) pictures of calcareous nannofossils from Gurpi Fm. in Chamab stratigraphic section. Scale bar is 5 µm. (A) *Tranolithus orionatus*, (5º rotated), (XPL), Sample No. 39; (B) *Reinhardtites anthophorus*, (XPL), Sample No. 42; (C) *Reinhardtites levis,* (XPL), Sample No. 44; (D) *Eiffellithus turriseiffelii*, (30º rotated), (XPL), Sample No. 38; (E) *Rhagodiscus angustus,* (XPL), Sample No. 14; (F) *Retecapsa crenulata,* (XPL), Sample No. 35; (G) *Manivitella pemmatoidea,* (XPL), Sample No. 18; (H) *Watznaueria barnesiae,* (XPL); Sample No. 86; (I) *Cyclogelosphaera* Cf. *Cy. rotaclypeata*, (XPL), Sample No. 103; (J) *Watznaueria barnesiae* & *Aspidolithus parcus constrictus*, (XPL), Sample No. 26; (K) *Watznaueria barnesiae,* (XPL), Sample No. 18; (L) *Aspidolithus parcus constrictus*, (XPL), Sample No. 40; (M) *Arkhangelskiella cymbiformis*, (XPL), Sample No. 39; (N) *Arkhangelskiella cymbiformis,* (PPL), Sample No. 42; (O) *Aspidolithus parcus parcus*, (10º rotated), (XPL), Sample No. 8; (P) *Aspidolithus parcus constrictus*, (10º rotated), (XPL), Sample No. 27; (Q) *Calculites obscurus,* (40º rotated), (XPL), Sample No. 44; (R) *Calculites obscurus,* (XPL), Sample No. 39; (S) *Braarudosphaera bigelowii*, (XPL), Sample No. 82; (T) *Lithraphidites carniolensis,* (30º rotated), (PPL), Sample No. 35.

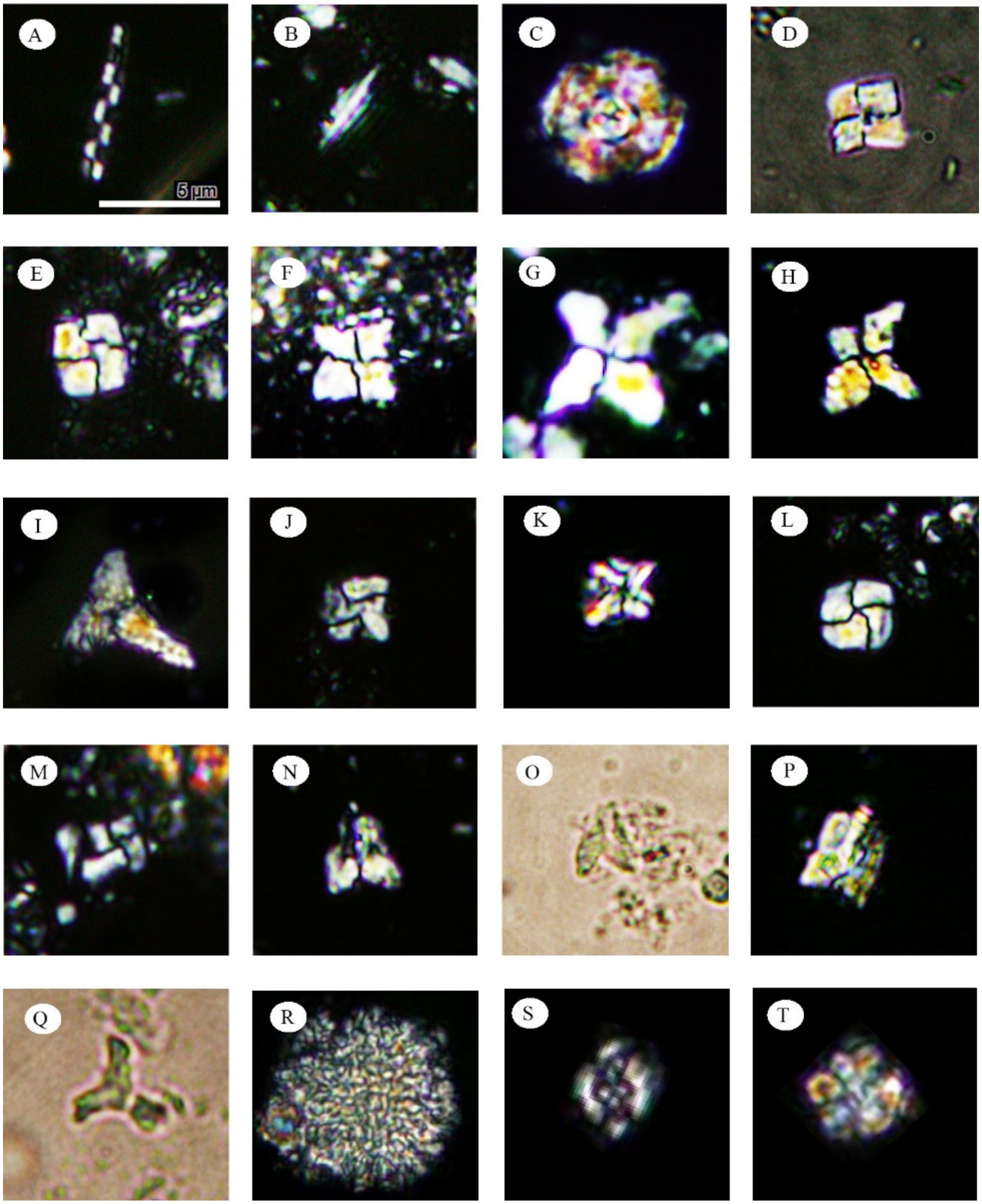


Plate 2: Cross polarised light (XPL) and plane polarised light (PPL) pictures of calcareous nannofossils from Gurpi Fm. in Chamab stratigraphic section. Scale bar is 5 µm. (A) *Microrhabdulus decoratus*, (20º rotated), (XPL), Sample No. 34; (B) *Lithraphidites quadratus*, (XPL), Sample No. 61; (C) Nannoconus top view, (XPL), Sample No. 1; (D) & (E) *Uniplanarius gothicus*, (XPL), Sample No. 36; (F) *Uniplanarius sissinghii*, (XPL), Sample No. 27; (G) *Uniplanarius sissinghii*, (XPL), Sample No. 34; (H) *Uniplanarius sissinghii*, (XPL), Sample No. 37; (I) *Uniplanarius trifidus*, (XPL), Sample No. 43; (J) *Micula murus*, (XPL), Sample No. 78; (K) *Micula decussata*, (XPL), Sample No. 62; (L) *Micula praemurus*, (XPL), Sample No. 59; (M) *Micula prinsii,* (XPL), Sample No. 79; (N) *Ceratolithoides aculeus*, (XPL), Sample No. 35; (O) *Ceratolithoides aculeus*, (PPL), Sample No. 37; (P) *Ceratolithoides* sp., (30º rotated), (XPL), Sample No. 34; (Q) *Marthasterites furcatus*, (PPL), Sample No. 8; (R) *Thoracosphaera operculata*, (XPL), Sample No. 94; (S) *Cruciplacolithus tenuis*, (XPL), Sample No. 86; (T) *Biantholithus sparsus*, (XPL), Sample No. 86.

e. Quadrum trifidum Zone (CC22/UC15d, e^{TP}), late late Campanian

This biozone is identified from the FO of *Uniplanarius trifidus* (94.2 m, Sample No. 35) to the LO of *Reinhardtites anthophorus* (121.1 m, Sample No. 44) which is dedicated to the late late Campanian. This zone is equivalent to subzones UC15d^{TP} and UC15e^{TP} of the Burnett zonation (1998). According to the Burnett zonation (1998), the FO of *Eiffellithus parallelus* at the beginning of subzone UC15e^{TP} was not recorded. In this zone, the last occurrence of *Lithastrinus grillii* was recorded at 104 m (Sample No. 39). The thickness of this zone was measured to be 27 m (Sample Nos. 35 to 44).

In the studied section, at the middle of the Gurpi Fm. from 121.1 m to 160 m, which mainly consists of limestone (Seymareh Limestone, at the top of nannofossil zone CC22), defining a marked interval with a scarcity of calcareous nannofossils is identified. In this interval, diagenesis completely eliminates calcareous nannofossils, so this interval is completely barren of calcareous nannofossils, and there is a gap between CC22 and CC25b zones.

f. Arkhangelskiella cymbiformis Zone (CC25b, c/UC20a, b^{TP}), early late Maastrichtian

The Arkhangelskiella cymbiformis Zone is defined as being from the LO of *Reinhardtites levis* (121 m, Sample No. 44) to the first occurrence of *Nephrolithus frequens* according to Perch-Nielsen (1985). In these strata, *Nephrolithus frequens* were not recorded. After recording the LO of *Reinhardtites anthophorus*, no zone was determined due to the lack of nannofossil assemblages. Therefore, the LO of *Reinhardtites levis* at the beginning of CC25 was not recorded. Then, gradually towards the top of the formation we have the first occurrence of species such as *Lithraphidites quadratus* (160.1 m, Sample No. 59) and *Micula murus,* respectively. Therefore, this interval, due to the FO of *Lithraphidites quadratus* and then the FO of *Micula murus* (177 m, Sample No. 63) is equivalent to subzones CC25b and CC25c of the Sissingh zonation (1977). This zone is equivalent to UC20a, b^{TP} of the Burnett zonation (1998). The age of this biozone is early late Maastrichtian with approximately 17 m thick (Sample Nos. 59 to 63).

g. Nephrolithus frequens Zone (CC26/UC20c, d^{TP}), late late Maastrichtian

The next bio-zone recorded in the Gurpi Fm. is zone CC26, which is defined as the interval from the first occurrence to the last occurrence of *Nephrolithus frequens* (Perch-Nielsen, 1985). According to Perch-Nielsen (1985a), *Nephrolithus frequens* is not recognizable in low latitudes and as mentioned above, *Nephrolithus frequens* were not recorded in this section. In this study, the FO of *Ceratolithoides kamptneri* was not detected, and accordingly, UC20c^{TP} subzone was not recognized. The FO of *Micula prinsii* (200.1 m, Sample No. 78) was detected and can be used to determine the lower part of CC26b subzone at the late late Maastrichtian. The upper limit of the zone was indicated by the LO of Cretaceous taxa (217 m, Sample No. 82) or the FO of Paleogene species such as *Biantholithus sparsus* and *Cruciplacolithus tenuis* (217.8 m, Sample No. 86). The Nephrolithus frequens Zone is equivalent of UC20c^{TP} and UC20d^{TP} subzones of the Burnett zonation (1998). Some of the species in this zone are *Micula murus, Micula prinsii, Thoracosphaera operculata* and *Braarudosphaera bigelowii*. The thickness of this zone was measured to be 16.9 m (Sample Nos. 78 to 82) and the age of that is late late Maastrichtian.

In this zone, the FO of *Micula prinsii* (200.1 m, Sample No. 78) and the LO of Cretaceous nannoflora mark the boundaries of subzone CC26b and are considered to be the closest calcareous nannofossil event to approximate the K/Pg boundary. In this study, the FO of *Biantholithus sparsus* together *Cruciplacolithus tenuis* and *Cruciplacolithus primus* were recorded at 217.8 m in the base of NP2 biozone. At the top of this biozone, between thickness 217 m and 217.8 m, a biostratigraphic break is present between the LO of *Micula prinsii* (217 m, Sample No. 82) to the FO of *Cruciplacolithus tenuis* (217.8 m, Sample No. 86). About 0.8 m limestone (from 217 to 217.8 m), separates upper Cretaceous (CC26b subzone) and lower Paleocene sediments (NP2). The interval is marked by a clear break in the nannofossil assemblage and by distinct changes in lithology (Fig. 3).

h. Cruciplacolithus tenuis Zone (NP2/ equivalent with CNP2- lower part of CNP3), early Danian

The NP2 Zone has been expanded from the FO of *Cruciplacolithus tenuis* (217.8 m, Sample No. 86) to the FO of *Chiasmolithus danicus* (224.7 m, Sample No. 95), according to standard scheme of Martini (1971). This zone is equivalent to CNP2 and the lower part of CNP3of the Agnini *et al.*'s (2014) zonation. The FO of *Coccolithus pelagicus* (218 m, Sample No. 87), marks the base of the CNP2 of the Agnini *et al.* (2014) zonation. The FO of *Praeprinsius dimorphosus* marks the CNP2 was not recorded at the studied interval. The age of zone is early Danian. The thickness of this zone has been measured as approximately 7 m (Sample Nos. 86 to 95).

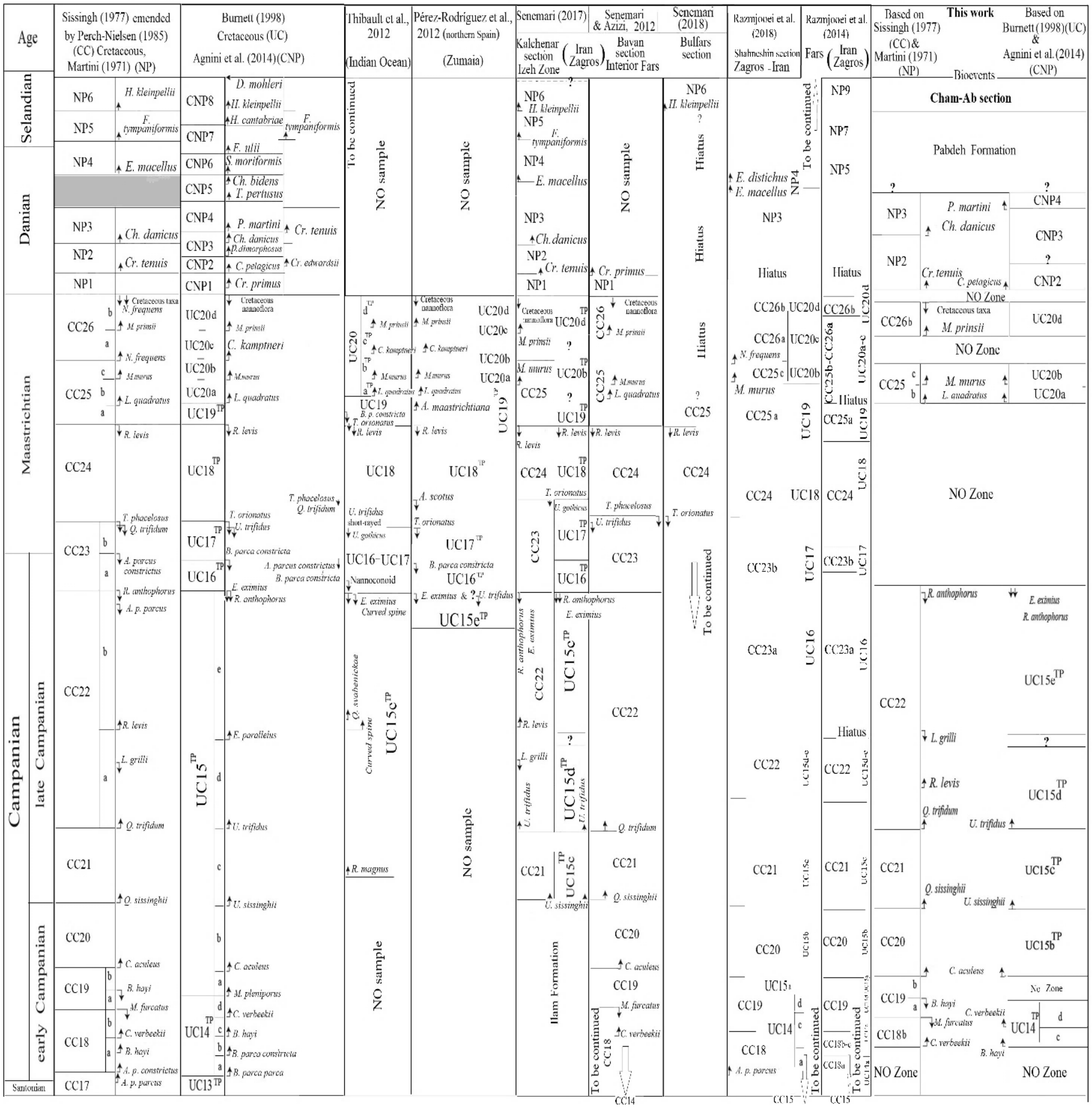
i. Chiasmolithus danicus Zone (NP3/CNP3 -CNP4), late Danian

The last nannofossil zone recorded in the Gurpi Fm. is Chiasmolithus danicus Zone. This bio-zone has been expanded from the FO of *Chiasmolithus danicus* (224.7 m, Sample No. 95) to the FO of *Ellipsolithus macellus*, and equivalent to the upper part of CNP3 of Agnini *et al.* (2014) zonation. However, in this study, *Ellipsolithus macellus* was not recorded. Therefore, the top of this zone (NP3) has not been determined. The FO of *Prinsius martini* (228 m, Sample No. 100) can be used to determine the top of CNP3 Zone. The age of this zone is late Danian.

Discussion

Calcareous nannofossils show a broad distribution and rapid evolution in the Mesozoic and Cenozoic eras (Perch-Nielsen, 1985). In this study, the extensive presence of calcareous nannofossils at the Gurpi Fm. indicates suitable living conditions in sea water. The calcareous nannofossil assemblages at the lower part of the Gurpi Fm. (CC18 to CC22 zones), demonstrates the presence of the upper Cretaceous strata (Table 1). These zones are followed by subzones CC25b, CC25c, and CC26b. Additionally, in this study, the first occurrence of *Micula prinsii,* which marks the base of subzone CC26b, and also the occurrence of *Micula murus* before it, are proof that the late Maastrichtian had warm conditions (Self-Trail, 2001; Sheldon *et al.,* 2010). In this regard, the middle part of the Gurpi Fm. is characterized by limestone and indicates both a decrease in water depth as well as a decrease in calcareous nannofossils indicators. In fact, in this part, lithology has changed (from shale and marl to limestone), so nannofossil species are not observed. Therefore, at some intervals, from late Campanian to early Danian, it is impossible to identify bio-zones (Fig. 3). Nevertheless, some bio-events were recorded towards the K/Pg boundary. Towards the uppermost part of Gurpi Fm., the earliest Danian zone, or NP1 zone, is missing. Therefore, in the Cham-Ab section, the Cretaceous-Paleogene boundary has been determined as a biostratigraphic gap. In other words, there is not a continuous record through the late Maastrichtian to the early Danian, and a gap has been recognized between them. Subsequently, an interval was identified with a number of Danian calcareous nannofossils (NP2 - NP3). In this section, the occurrence of *Cruciplacolithus tenuis* and *Chiasmolithus danicus* were recorded at the upper part of Gurpi Fm. in the studied section, indicating NP2 and NP3 zones. However, due to the lack of *Ellipsolithus macellus* marker for the top of NP3, up to the top of Gurpi Fm. was considered for NP3 bio-zone. Therefore, between CC22 and CC25b biozones, and CC26b and NP2 biozones, barren intervals, or interval without calcareous nannofossils were identified. In this research, the biostratigraphy of the studied section was compared to the existing zonations of the Indian Ocean (Thibault *et al.,* 2012), Spain (Perez-Rodriguez *et al.,* 2012), the Zagros Basin (Senemari & Azizi, 2012; Razmjooei *et al*., 2014; Senemari, 2017; Razmjooei *et al.,* 2018 and Senemari, 2018), and with the standard zonations of Campanian – Maastrichtian boundary published by Sissingh (1977), Perch- Nielsen (1985), and Burnett (1998), and likewise with those of the Paleogene from Martini (1971), and Agnini *et al.* (2014) for the Tethyan realm (Table 2). The age of the Gurpi Fm. is varying from the Santonian to the Selandian at different parts of the Zagros Basin, allowing us to recognize several bio-zones within this time interval. At the studied interval, NP1 is not recorded at the upper part of the Gurpi Fm. in the early Danian, while in some of the previous studies (e.g., Fars and Izeh Provinces) a continuous trend can be observed between Cretaceous (CC26) and the Paleogene (NP1) (Senemari & Azizi, 2012; Senemari, 2017). In the interior Fars (Bavan section), Senemari & Azizi (2012) delineated a continuous trend through the late Maastrichtian to the early Danian. Senemari (2017) also, recorded continuity during the latest Maastrichtian to the early Danian in the Kalchenar section, in Izeh Province. In fact, Table 2 demonstrates the correlation of bio-events at the Gurpi Fm. in the Zagros Basin with other locations in the Tethyan realm.

Table 2. Comparison between early Campanian to late Danian calcareous nannofossils standard zonation schemes of the Tethyan realm with biozonation established for the studied section in the Zagros Basin.



Conclusion

This study was concentrated on the Gurpi Fm. which mainly consists of marly shales and limestones at the Cham-Ab section in southwest Ilam Province, in the Zagros Basin. As a result of this study, 28 genera and 45 species of calcareous nannofossils have been identified, all of which are often indicative of low latitude. Based on calcareous nannofossil biostratigraphy the studied section can be divided into the following bio-zones: CC18b (UC14c^{TP} -UC14d^{TP}), CC19 (UC14d^{TP} - UC15a^{TP}), CC20 (UC15b^{TP}), CC21 (UC15c^{TP}), CC22 (UC15d^{TP} -UC15e^{TP}), CC25b-c (UC20a^{TP} - UC20b^{TP}), CC26b (UC20d^{TP}) of the Sissingh (1977) and the Burnett (1998) zonations, respectively. Subsequently, zones of the NP2 (CNP2- CNP3) and NP3 (CNP3 - CNP4) of the Martini (1971) and the Agnini *et al.* (2014) zonations, indicated that the examined sequence is early Campanian - late Danian. The Cretaceous -

Paleogene boundary is identified as an unconformity at the studied interval which is marked by a biostratigraphic interruption.

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Appendix

Taxonomic Index

Taxonomic list includes all the taxa cited in the paper. The taxonomy and bibliographical references follow in Perch-Nielsen (1985) and Agnini *et al.* (2014).

*Arkhangelskiella cymbiformis*Vekshina, 1959
Aspidolithus parcus parcus (Stradner 1963) Noël 1969
Aspidolithus parcus constrictus (Hattner *et al.,* 1980) Perch-Nielsen (1984)
Biantholithus sparsus Bramlette & Martini, 1964
Braarudosphaera bigelowii (Gran & Braarud 1935) Deflandre, 1947
Broinsonia parca constricta Hattner *et al.,* 1980
Broinsonia parca parca Stradner (1963) Bukry, 1969
Bukryaster hayi (Bukry, 1969) Prins & Sissingh in Sissingh, 1977
Ceratolithoides arcuatus Prins & Sissingh in Sissingh, 1977
Ceratolithoides aculeus (Stradner, 1961) Prins & Sissingh in Sissingh, 1977
Ceratolithoides verbeekii Perch-Nielsen, 1979
Chiasmolithus danicus (Brotzen, 1959) Hay & Mohler, 1967
Chiastozygus platyrhethus Hill, 1976
Coccolithus pelagicus (Wallich 1877) Schiller, 1930
Cruciplacolithus primus Perch-Nielsen, 1977
Cruciplacolithus tenuis (Stradner, 1961) Hay and Mohler *in* Hay *et al.,* 1967
Eiffellithus eximius (Stover, 1966) Perch-Nielsen, 1968
Eiffellithus gorkae Reinhardt, 1965
Eiffellithus turriseiffelii (Deflandre *in* Deflandre & Fert, 1954) Reinhardt, 1965
Lithraphidites carniolensis Deflandre, 1963
Lucianorhabdus cayeuxii Deflandre, 1959
Lithastrinus grillii Stradner, 1962
Lithraphidites quadratus Bramlette & Martini, 1964
*Markalius inversus (*Deflandre *in* Deflandre & Fert, 1954) Bramlette Martini (1964)
Marthasterites furcatus (Deflandre *in* Deflandre & Fert, 1954) Deflandre, 1959
Microrhabdulus decoratus Deflandre (1959)
Micula concava (Stradner *in* Martini & Stradner, 1960) Verbeek, 1976
Micula decussata Vekshina, 1959
Micula murus (Martini, 1961) Bukry, 1973
*Micula praemurus (*Bukry, 1973) Stradner & Steinmetz (1984)
Micula prinsii Perch-Nielsen, 1979
Micula staurophora (Gardet, 1955) Stradner, 1963
Prediscosphaera cretacea (Arkhangelsky, 1912) Gartner, 1968
Prinsius martinii (Perch-Nielsen, 1969) Haq, 1971
Placozygus sigmoides (Bramlette & Sullivan, 1961) Romein 1979
Quadrum gothicum Deflandre 1959
Quadrum sissinghii Perch-Nielsen, 1986
Quadrum trifidum (Stradner In Stradner & Papp 1961) Prins & Perch-Nielsen in Manivit et al. 1977
Reinhardtites levis Prins & Sissingh in Sissingh, 1977
Reinhardtites anthophorus (Deflandre, 1959) Perch-Nielsen, 1968
Rhagodiscus angustus (Stradner, 1963) Reinhardt, 1971
Thoracosphaera operculata Bramlette & Martini (1964)
Tranolithus orionatus Reinhardt (1966a) Reinhardt, 1966b
Tranolithus phacelosus Stover (1966)
Uniplanarius gothicus Deflandre (1959) Hattner & Wise, in Wind & Wise, 1983
Uniplanarius sissinghii Perch-Nielsen (1986) Farhan, 1987
Uniplanarius trifidus Stradner *in* Stradner & Papp (1961) Hattner & Wise, in Wind & Wise, 1983)
Watznaueria barnesiae (Black *in* Black & Barnes, 1959) Perch-Nielsen, 1968
Watznaueria biporta Bukry, 1969
Zeugrhabdotus sigmoides Bramlette & Sullivan (1961) Bown & Young, 1997